Bacteria TMDL Development for Crooked Run, Borden Marsh Run, Willow Brook, West Run, Long Branch, Stephens Run, Manassas Run, and Happy Creek Watersheds, and Sediment TMDL Development for Happy Creek Watershed Located in Clarke, Frederick, and Warren Counties, Virginia

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Background

Section 303(d) of the Clean Water Act (CWA) and the United States Environmental Protection Agency's Water Quality Planning and Management Regulations require states to develop total maximum daily loads (TMDLs) for waterbodies that are exceeding water quality standards (WQSs). TMDLs represent the total pollutant loading a waterbody can receive without violating WQSs.

Eight Shenandoah River tributaries were listed as impaired on Virginia's 2012 Section 303(d) Report on Impaired Waters due to water quality violations of the *E.* coli standard. These impaired stream segments include Borden Marsh Run (VAV-B55R_BMR01A00), Crooked Run (VAV-B56R_CRO01A00), Happy Creek (VAV-B41R_HPY01A00 & VAV-B41R_HPY02A00), Long Branch (VAV-B57R_LNG01A04), Manassas Run (VAV-B55R_MAN01A00 & VAV-B55R_MAN02A04), Stephens Run (VAV-B56R_STV01A00), West Run (VAV-B56R_WST01A00), and Willow Brook (VAV-B55R_WLO01A06). The Shenandoah River tributaries watersheds are approximately 67,588 acres in size and cover portions of Frederick County, Clarke County, and Warren County, including the Town of Front Royal.

Happy Creek was also listed as impaired due to water quality violations of the general aquatic life (benthic) standard in the 2012 Virginia Water Quality Assessment 305(b)/303(d) Integrated Report (VADEQ, 2012). The Virginia Department of Environmental Quality (DEQ) has delineated the benthic impairment as 8.42 miles on Happy Creek (stream segments VAV-B41R_HPY01A00 and VAV-B41R_HPY02A00).

This document describes the Total Maximum Daily Loads (TMDLs) for bacteria that were developed for Borden Marsh Run, Crooked Run, Happy Creek, Long Branch, Manassas Run, Stephens Run, West Run, and Willow Brook watersheds in order to address the bacteria water quality impairments. The TMDLs were developed for the water quality standard for bacteria, which states that the calendar-month geometric mean concentration of *E. coli* shall not exceed 126 cfu/100 mL.

Since a benthic impairment is based on a biological inventory, rather than on a physical or chemical water quality parameter, the pollutant is not explicitly identified in the assessment, as it is with physical and chemical parameters. This document describes the process used to identify the most probable stressor contributing to the impairment of the benthic community in Happy Creek and the development of the TMDL to address the pollutant. Sediment has been identified as the most probable stressor and a sediment TMDL has been developed to address the Happy Creek biological impairment.

A glossary of terms used in the development of this TMDL is listed in Appendix A.

Pollutant Sources

Sources of fecal bacteria were identified throughout the watershed defining the entire study area. Multiple permitted point discharges of fecal bacteria were identified in the study area. Other potential sources of fecal bacteria in the watershed are characterized as nonpoint sources including livestock, wildlife, manure and biosolids applications, pets, failing septic systems, spills, and straight pipe discharges.

As a result of the stressor analysis, the most probable stressor contributing to the impairment of the benthic community in Happy Creek was identified as sediment. Sediment was selected as the most probable stressor to Happy Creek based on poor riparian vegetation habitat metrics at both sites, along with poor bank stability metrics at the upstream site, poor channel alteration metric scores, and moderate impacts on the LRBS siltation metric shown at the downstream site.

Modeling

The Hydrological Simulation Program – FORTRAN (HSPF) (Bicknell *et al.*, 2001) was used to simulate the fate and transport of fecal coliform bacteria in the Shenandoah River tributaries watersheds. HSPF is a continuous model that can represent fate and transport of pollutants on both the land surface and in the stream. As recommended by the Virginia Department of Environmental Quality (VADEQ), water quality modeling was conducted with fecal coliform inputs, and then a translator equation was used to convert the output to *E. coli* for the final TMDLs.

The Generalized Watershed Loading Functions (GWLF) model was used to simulate sediment loads in the Happy Creek watershed. The GWLF model is a continuous simulation model that uses daily time steps for weather data and water balance calculations. The GWLF model was run in metric units and converted to English units for this report.

Endpoints

The numerical criteria for *E. coli* are a *Geometric Mean* of 126 cfu/100 ml and a *Single Sample Maximum* of 235 cfu/100 ml. The endpoints were established based on the designated use of primary contact recreation (i.e., swimming and fishing). The calendar-month geometric mean *E. coli* criterion (126 cfu/100 mL) with zero violations is the endpoint for the development of TMDL allocation scenarios. A 10.5% violation rate of the instantaneous *E. coli* water quality criterion (235 cfu/100 mL) served as the endpoint for development of Stage 1 implementation scenarios, which allow for an evaluation of the effectiveness of management practices and accuracy of model assumptions through data collection.

Since there are no in-stream water quality standards for sediment in Virginia, an alternate method was needed for establishing a reference endpoint that would represent the “non-impaired” condition. For the Happy Creek sediment impairments, the procedure used to set TMDL sediment endpoint loads is a modification of the methodology used to address sediment impairments in Maryland’s non-tidal watersheds (MDE, 2006, 2009), hereafter referred to as the “all-forest load multiplier” (AllForX) approach.

The Bacteria TMDLs

Various source reduction scenarios were evaluated to identify implementable scenarios that meet the calendar-month geometric mean *E. coli* criterion (126 cfu/100 mL) with zero violations. These scenarios were conducted using the same meteorological data used to establish existing conditions. The bacteria loadings used in modeling correspond to anticipated and permitted future conditions for Borden Marsh Run, Crooked Run, Happy Creek, Long Branch, Manassas Run, Stephens Run, West Run, and Willow Brook. Equation ES.1 was used to calculate the TMDL allocations shown in Table ES.1.

$$TMDL = WLA_{total} + LA + MOS \qquad [ES.1]$$

Where:

WLA_{total} = waste load allocation (point source contributions, including future growth);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety.

Table ES.1. Annual *E. coli* loadings (cfu/yr) for the TMDLs.

Impairment	WLAtotal	LA*	MOS**	TMDL
Borden Marsh Run	2.81×10^{11}	1.37×10^{13}	--	1.40×10^{13}
Crooked Run	2.22×10^{12}	6.39×10^{13}	--	6.61×10^{13}
Happy Creek	4.27×10^{11}	2.09×10^{13}	--	2.13×10^{13}
Long Branch	1.73×10^{11}	8.48×10^{12}	--	8.66×10^{12}
Manassas Run	3.24×10^{11}	1.42×10^{12}	--	1.45×10^{13}
Stephens Run	3.07×10^{11}	1.39×10^{13}	--	1.42×10^{13}
West Run	5.80×10^{11}	2.24×10^{13}	--	2.30×10^{13}
Willow Brook	2.33×10^{11}	1.13×10^{13}	--	1.16×10^{13}

*The LA is the remaining loading allowed after the MOS and WLA are subtracted from the TMDL as determined for the downstream end of the impaired segment, the watershed outlet. This value is different from the tables providing nonpoint source load (Tables ES.3 – ES.18) because of factors such as bacteria die off that occur between the point of deposition and the modeled watershed outlet.

**Implicit MOS

The Sediment TMDL for Happy Creek

The sediment TMDL for Happy Creek was also calculated using Equation ES.1. The sediment TMDL load for the Happy Creek watershed was calculated as the value of AllForX, the point where the regression line between AllForX and the VSCI intersected the VSCI impairment threshold (VSCI = 60), times the all-forest sediment load of each TMDL watershed. The Happy Creek TMDL load and its components are shown in Table ES.2.

Table ES. 2. Happy Creek sediment TMDL.

Impairment	TMDL	WLA		LA	MOS
	Sediment Load (tons/yr)				
Cause Group Code B41R-03-BEN					
Happy Creek	2,511.3	29.05		2,289.8	192.4
VAC-B41R_HPY01A00		VAR050852 Zuckerman Metals, Inc.	2.52 tons/yr		
VAC-B41R_HPY02A00		construction aggregate WLA	1.42 tons/yr		
		Future Growth WLA	25.11 tons/yr		

Margin of Safety

To allocate loads while protecting the aquatic environment, a margin of safety (MOS) needs to be considered. An implicit MOS was included in the bacteria TMDLs for Borden Marsh Run, Crooked Run, Happy Creek, Long Branch, Manassas Run, Stephens Run, West Run, and Willow Brook watersheds.

The sediment TMDL MOS was set equal to the difference between the value of AllForX at VSCI = 60 and the value of AllForX at the lower confidence interval limit, multiplied times the all-forest sediment load for each watershed, amounting to 7.7% of the TMDL.

Allocation Scenarios

The proposed scenarios for the bacteria TMDLs require load reductions only for nonpoint sources of *E. coli*. The difference between the TMDL and the existing annual load represents the necessary level of *E. coli* reduction. Details on the loads to be reduced from each source are given in Table ES.3 through Table ES.18.

Table ES. 3. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Borden Marsh Run.

Land use category	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($\times 10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($\times 10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Cropland	18	1	10	45
Pasture	3,171	97	1,173	63
Hayland	12	<1	12	0
Developed	42	1	12	70
Transportation	1	<1	1	0
Forest	13	<1	13	0
Total	3,257		1,221	63

Table ES. 4. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Crooked Run.

	Existing Conditions		Allocation Scenario	
Land use category	**Existing Conditions Load ($x10^{12}$ cfu/yr)**	**Percent of total land deposited load from nonpoint sources**	**TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)**	**Percent Reduction from Existing Load**
Cropland	64	1	55	15
Pasture	4,433	89	2,438	45
Hayland	47	1	47	0
Developed	363	7	327	10
Transportation	1	<1	1	0
Forest	89	2	89	0
Total	4,997		2,957	41

Table ES. 5. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Happy Creek.

	Existing Conditions		Allocation Scenario	
Land use category	**Existing Conditions Load ($x10^{12}$ cfu/yr)**	**Percent of total land deposited load from nonpoint sources**	**TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)**	**Percent Reduction from Existing Load**
Cropland	6	<1	5	10
Pasture	1,587	61	714	55
Hayland	3	<1	3	0
Developed	890	34	133	85
Transportation	1	<1	1	0
Forest	116	4	116	0
Total	2,603		972	63

Table ES. 6. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Long Branch.

	Existing Conditions		Allocation Scenario	
Land use category	**Existing Conditions Load ($x10^{12}$ cfu/yr)**	**Percent of total land deposited load from nonpoint sources**	**TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)**	**Percent Reduction from Existing Load**
Cropland	114	1	97	15
Pasture	9,574	99	1,915	80
Hayland	7	<1	7	0
Developed	16	<1	16	0
Transportation	0	0	0	0
Forest	7	<1	7	0
Total	9,718		2,042	79

Table ES. 7. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Manassas Run.

Land use category	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Cropland	4	<1	4	10
Pasture	1,179	76	589	50
Hayland	2	<1	2	0
Developed	284	18	284	0
Transportation	1	<1	1	0
Forest	84	5	84	0
Total	1,554		964	38

Table ES. 8. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Stephens Run.

Land use category	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Cropland	28	1	23	15
Pasture	2,219	86	1,287	42
Hayland	88	3	88	0
Developed	236	9	213	10
Transportation	1	<1	1	0
Forest	25	1	25	0
Total	2,597		1,637	37

Table ES. 9. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for West Run.

Land use category	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Cropland	21	<1	18	15
Pasture	4,277	94	2,138	50
Hayland	19	<1	19	0
Developed	142	3	142	0
Transportation	1	<1	1	0
Forest	84	2	84	0
Total	4,544		2,402	47

Table ES. 10. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Willow Brook.

Land use category	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Cropland	10	<1	9	15
Pasture	2,696	97	1,483	45
Hayland	8	<1	8	0
Developed	44	2	44	0
Transportation	0	0	0	0
Forest	12	<1	12	0
Total	2,770		1,556	44

Table ES. 11. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Borden Marsh Run.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	11.6	77	0.1	99
Wildlife in Streams	3.4	23	3.4	0
Straight Pipes	0	0	0	100
Total	15.0		3.5	77

Table ES. 12. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Crooked Run.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	3.6	59	0.9	74
Wildlife in Streams	2.4	40	2.4	0
Straight Pipes	0.1	1	0	100
Total	6.1		3.3	45

Table ES. 13. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Happy Creek.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	4.2	37	0.6	85
Wildlife in Streams	6.7	60	5.0	25
Straight Pipes	0.3	3	0	100
Total	11.2		5.7	49

Table ES. 14. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Long Branch.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	3.6	74	0.4	89
Wildlife in Streams	1.3	26	1.3	0
Straight Pipes	0	0	0	100
Total	4.9		1.7	66

Table ES. 15. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Manassas Run.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	4.3	51	0.2	96
Wildlife in Streams	3.9	45	2.8	27
Straight Pipes	0.4	4	0	100
Total	8.6		3.0	65

Table ES. 16. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Stephens Run.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	1.2	44	0.7	44
Wildlife in Streams	1.3	46	1.3	0
Straight Pipes	0.3	10	0	100
Total	2.8		2.0	29

Table ES. 17. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for West Run.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	7.4	74	1.1	85
Wildlife in Streams	2.3	23	2.3	0
Straight Pipes	0.3	3	0.0	100
Total	18.5		3.4	66

Table ES. 18. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Willow Brook.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	5.8	73	0.3	95
Wildlife in Streams	2.1	27	2.1	0
Straight Pipes	0	0	0	100
Total	7.9		2.4	70

The target sediment load for each Happy Creek watershed allocation scenario is the TMDL minus the MOS. Allocation scenarios were created by applying percent reductions to the various land use/source categories until the target allocation load was achieved. Two allocation scenarios were created based on input from local stakeholders, Table ES. 19.

Table ES. 19. Sediment TMDL load allocation scenarios for Happy Creek.

Land Use/ Source Group	Existing Sediment Load (tons/yr)	Future Sediment Load (tons/yr)	Scenario 1		Scenario 2	
			% Reduction	Allocated Load	% Reduction	Allocated Load
Row Crops	211.5	208.6	37.2%	131.1		208.6
Pasture	909.3	883.6	37.2%	555.3	60.4%	349.7
Hay	735.1	714.4	37.2%	449.0		714.4
Forest	559.8	555.3		555.3		555.3
Harvested Forest	43.0	42.6	42.9%	24.4	42.9%	24.4
Developed	668.4	670.1	37.2%	421.1	60.4%	265.2
Transitional	143.8	162.7	25.0%	122.0	25.0%	122.0
Channel Erosion	47.6	50.2	37.2%	31.6		50.2
Permitted WLA	3.9	29.1		29.1		29.1
Total Load	**3,322.3**	**3,316.6**		**2,318.8**		**2,318.8**
Target Allocation Load =		**2,318.8**				
% Reduction Needed =		30.1%				

Future Implementation

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in attainment of water quality standards. This report represents the culmination of that effort for the bacteria impairments on Borden Marsh Run, Crooked Run, Happy Creek, Long Branch, Manassas Run, Stephens Run, West Run, and Willow Brook, and the sediment impairment on Happy Creek. The second step is to develop a TMDL implementation plan. The final step is to initiate recommendations outlined in the TMDL implementation plan and to monitor stream water quality to determine if water quality standards are being attained.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of VADEQ and other cooperating agencies.

Public Participation

Public participation was elicited at every stage of the TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. Technical Advisory Committee (TAC) meetings and public meetings were organized for this purpose. These meetings were held in various locations in Clarke County, Front Royal, Warren County, and via webinar.

Chapter 1: Introduction

1.1. *Background*

1.1.1. TMDL Definition and Regulatory Information

Section 303(d) of the Federal Clean Water Act and the U.S. Environmental Protection Agency's (USEPA) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to identify water bodies that violate state water quality standards and to develop Total Maximum Daily Loads (TMDLs) for such water bodies. A TMDL reflects the pollutant loading a water body can receive and still meet water quality standards. A TMDL establishes the allowable pollutant loading from both point and nonpoint sources for a water body, allocates the load among the pollutant contributors, and provides a framework for taking actions to restore water quality.

1.1.2. Bacteria Impairment Listing

Multiple Shenandoah River tributaries were listed as impaired on Virginia's 2012 Section 303(d) Report on Impaired Waters due to water quality violations of the E. coli standard. These impaired stream segments include Borden Marsh Run (VAV-B55R_BMR01A00), Crooked Run (VAV-B56R_CRO01A00), Happy Creek (VAV-B41R_HPY01A00 & VAV-B41R_HPY02A00), Long Branch (VAV-B57R_LNG01A04), Manassas Run (VAV-B55R_MAN01A00 & VAV-B55R_MAN02A04), Stephens Run (VAV-B56R_STV01A00), West Run (VAV-B56R_WST01A00), and Willow Brook (VAV-B55R_WL001A06). The Virginia Department of Environmental Quality (VADEQ) has described the impaired segments as presented in Figure 1.1 and Table 1.1.

Table 1.1. Impaired Segments Addressed in this TMDL report

Impaired Segment	Size	Initial Listing Year	Description
Borden Marsh Run (VAV-B55R_BMR01A00)	9.46 miles	2006	extending from its headwaters to its mouth on the Shenandoah River
Crooked Run (VAV-B56R_CRO01A00)	8.87 miles	2002	extending from the Lake Frederick dam to its confluence with the Shenandoah River
Happy Creek (VAV-B41R_HPY01A00 & VAV-B41R_HPY02A00)	8.42 miles	2004	extending from its headwaters to its confluence with the South Fork Shenandoah River
Long Branch (VAV-B57R_LNG01A04)	3.63 miles	2004	extending from its headwaters to its mouth on the Shenandoah River
Manassas Run (VAV-B55R_MAN01A00 & VAV-B55R_MAN02A04)	9.15 miles	2004	extending from its headwaters to its mouth on the Shenandoah River
Stephens Run (VAV-B56R_STV01A00)	0.95 miles	2010	extending from its confluence with an unnamed tributary to its confluence with Crooked Run
West Run (VAV-B56R_WST01A00)	6.12 miles	2010	extending from its headwaters to its confluence with Crooked Run
Willow Brook (VAV-B55R_WL001A06)	3.95 miles	2006	extending from its headwaters to its mouth on the Shenandoah River

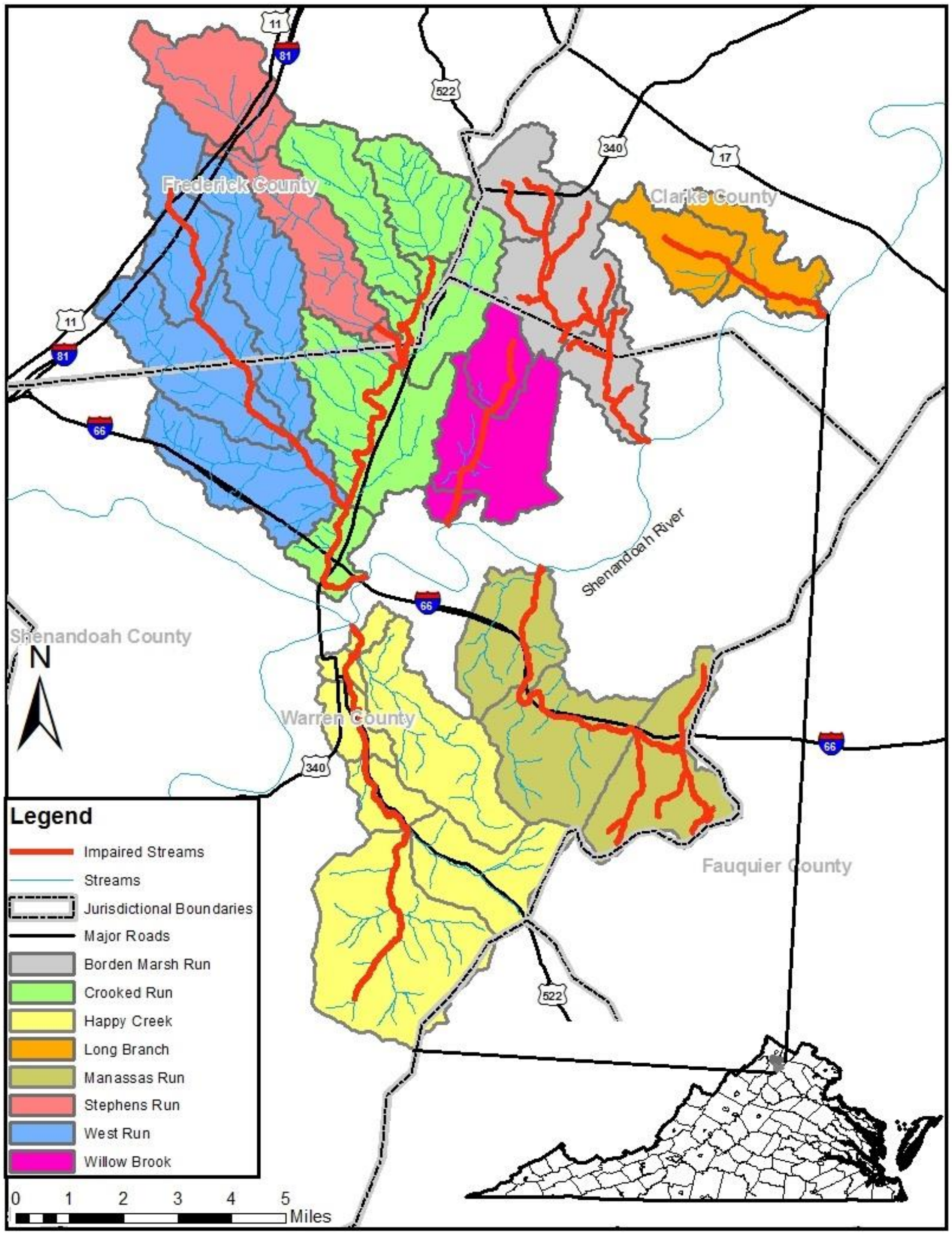

Figure 1.1. Impaired segments in Shenandoah River tributaries watersheds.

1.1.3. **Benthic Impairment Listing**

Two stream segments in the Happy Creek watershed in USGS Hydrologic Unit 02070005 were listed as impaired on Virginia's 2012 Section 303(d) Report on Impaired Waters due to water quality violations of the general aquatic life (benthic) standard. These impaired segments are located within the Shenandoah River Basin within Warren County in the Commonwealth of Virginia, and the watershed contains a majority of the Town of

Front Royal. The watershed delineated to simulate pollutant loads to these impaired segments is shown in Figure 1.2.

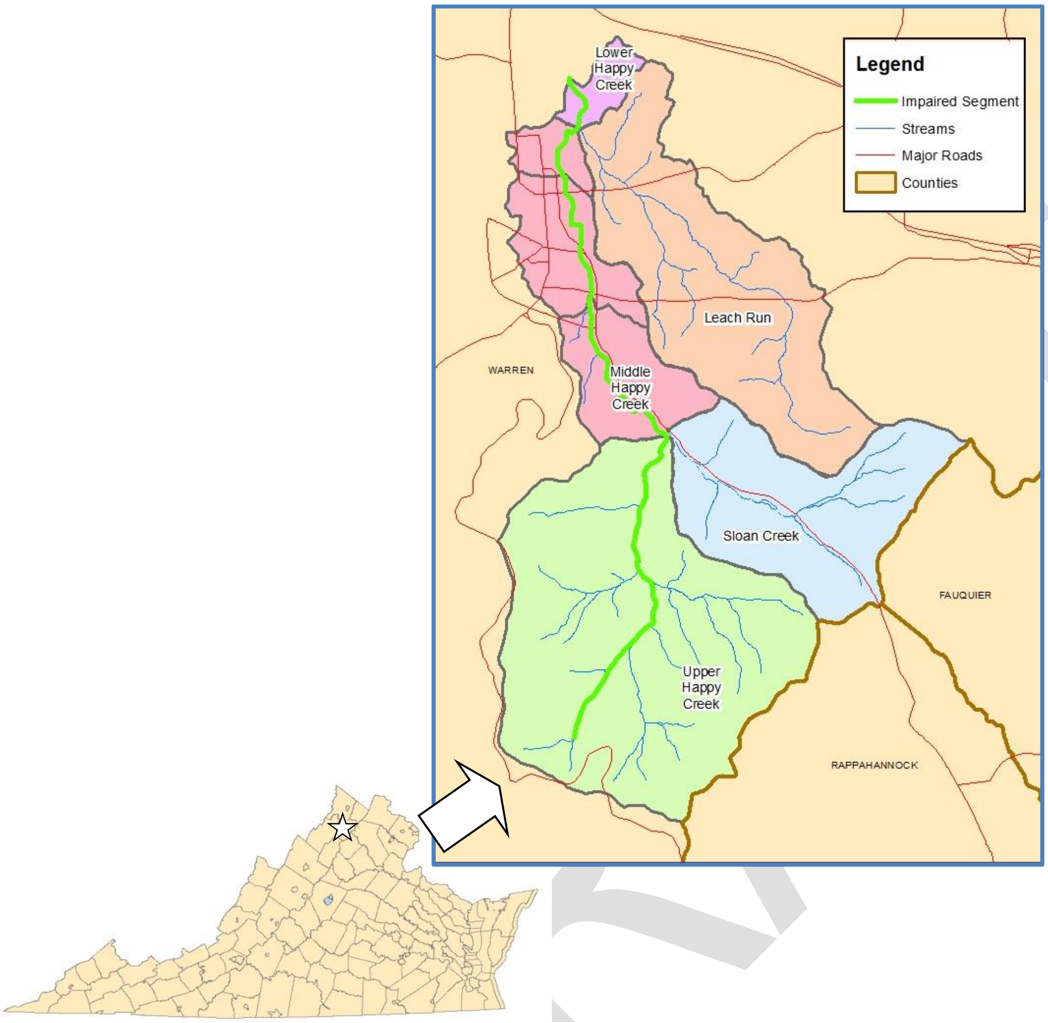

Figure 1.2. Location of benthic impaired segments in the Happy Creek watershed

Happy Creek was originally listed as impaired due to water quality violations of the general aquatic life (benthic) standard in the 2008 Virginia Water Quality Assessment 305(b)/303(d) Integrated Report (VADEQ, 2008). The Virginia Department of Environmental Quality (DEQ) has identified this impairment as Cause Group Code B41R-03-BEN, and delineated the benthic impairment as 8.42 miles on Happy Creek (stream segments VAC-B41R_HPY01A00 and VAC-B41R_HPY02A00). The Happy Creek impaired segments are contiguous and run from its headwaters downstream to its confluence with the South Fork Shenandoah River. A stressor analysis was performed that identified sediment as the pollutant of concern in addressing the benthic impairment.

The DEQ 2012 Fact Sheets for Category 5 Waters (VADEQ, 2012) state that Happy Creek is impaired based on assessments of the Virginia Stream Condition Index (VSCI) at biological stations 1BHPY001.29 and 1BHPY002.67. The sources of impairment are listed generically as agriculture and non-point sources.

1.1.4. **Watershed Location and Description**

The Shenandoah River study area is approximately 67,588 acres in size and covers portions of Frederick County, Clarke County and Warren County, and the Town of Front Royal. The Borden Marsh Run, Crooked Run, Long Branch, Manassas Run, Stephens Run, West Run, and Willow Brook watersheds are tributaries of the Shenandoah River. Happy Creek is a tributary of the South Fork Shenandoah River, which flows into the Shenandoah River. The watershed sizes are: Borden Marsh Run, 6,000 acres; Crooked Run, 30,252 acres (including West Run and Stephens Run); Happy Creek, 14,146 acres; Long Branch, 3,330 acres; Manassas Run, 9,434 acres; Stephens Run, 5,595 acres; West Run, 12,699 acres; Willow Brook, 4,426 acres. The watersheds associated with the individual impaired stream segments in this study are identified in **Error! Reference source not found.**Figure 1.1.

The predominant land uses in the Shenandoah River tributaries watersheds overall are forest (44.7%), agriculture (44.1%), and developed (13.5%).

The Borden Marsh Run watershed is predominantly agriculture (78.4%), with less significant forest (14.7%), and developed (6.2%). The land use distribution in the Crooked Run watershed, including the West Run and Stephens Run watersheds, consists mainly of agricultural area (47.2%), with developed land uses covering 39.4% of the area and developed land covering 12% of the watershed. The land use distribution in the Happy Creek watershed consists mainly of forested area (66.6%) with less significant area in developed (21.2%) and agriculture (11.7%). The land use in the Long Branch watershed consists mainly of agricultural uses (81.7%), with less significant portions in forest (14.1%) and development (4.1%). The Manassas Run watershed is predominately forested (71.3%) with less significant area in development (14.8%) and agriculture (13.3%). The land use distribution in Stephens Run consists mainly of agricultural land uses (57.2%) and forest (24.3%) with less significant area being developed (17.6%). The land use in

West Run consists mainly of agriculture (48.9%), forest (42.0%) and development (8.2%). Land use in the Willow Branch watershed is mainly agricultural (69.7%) with less significant area in forest (17.6%), and development (12.6%).

1.1.5. **Pollutants of Concern**

Pollution from both point and nonpoint sources can lead to *E. coli* bacteria contamination of water bodies. *E. coli* bacteria are found in the intestinal tract of warm-blooded animals; consequently, fecal waste of warm-blooded animals contains *E. coli*. Virginia has adopted an *Escherichia coli* (*E. coli*) water quality standard. The concentration of *E. coli* (a subset of the fecal coliform group) in water is considered to be a better indicator of pathogenic exposure than the concentration of the entire fecal coliform group in the water body. Even though most fecal coliform are not pathogenic, their presence in water indicates contamination by fecal material. Because fecal material may contain pathogenic organisms, water bodies with *E. coli* bacteria are potential sources of pathogenic organisms. For contact recreational activities such as boating and swimming, health risks increase with increasing *E. coli* counts. If the *E. coli* concentration in a water body exceeds state water quality standards, the water body is listed for violation of the state bacteria standard for contact recreational uses.

Pollution from both point and nonpoint sources can lead to a violation of the benthic standard. A violation of this standard is assessed on the basis of measurements of the in-stream benthic macro-invertebrate community. Water bodies having a benthic impairment are not fully supportive of the aquatic life designated use for Virginia's waters.

1.2. ***Designated Uses and Applicable Water Quality Standards***

1.2.1. **Designation of Uses (9 VAC 25-260-10)**

"A. All State waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish." SWCB, 2011.

Borden Marsh Run, Crooked Run, Happy Creek, Long Branch, Manassas Run, Stephens Run, West Run, and Willow Brook do not support the recreational (primary contact) designated use due to violations of the bacteria standard. Happy Creek also does not support the aquatic life designated use based on biological monitoring of the benthic macro-invertebrate community.

1.2.2. **Bacteria Standard (9 VAC 25-260-170)**

EPA has recommended that all states adopt an *E. coli* or enterococci standard for fresh water and enterococci criteria for marine waters, because there is a strong correlation between the concentration of these organisms (*E. coli* and enterococci) and the incidence of gastrointestinal illness. *E. coli* and enterococci are bacteria that can be found in the intestinal tract of warm-blooded animals and are subsets of the fecal coliform and fecal streptococcus groups, respectively. In line with this recommendation, Virginia adopted and published revised bacteria criteria on June 17, 2002. The revised criteria became effective on January 15, 2003. As of that date, the *E. coli* standard described below applies to all freshwater streams in Virginia.

For a non-shellfish water body to be in compliance with Virginia's revised bacteria standards the following criterion shall apply to protect primary contact recreational uses (SWCB, 2011):

***Escherichia coli* Standard:**

E. coli bacteria concentrations for freshwater shall not exceed a monthly geometric mean criterion of 126 colony forming units (cfu) per 100 mL. During any assessment period, if more than 10.5% of a station's samples exceed the single-sample maximum criterion, 235 *E. coli* cfu/100mL, the stream segment associated with that station is classified as impaired and a TMDL must be developed and implemented to bring the station into compliance with the water quality standard. There are nine ambient monitoring stations in the impaired Shenandoah River tributaries watersheds that were used to assess and list the study streams as impaired: two on Happy Creek and one on each of the other streams.

For the 2012 assessment period, January 2005 through December 2010, all of the stations had a violation rate greater than 10.5% of the single-sample maximum criterion concentration of 235 cfu/100ml, leading to the impaired classification for the Borden Marsh Run, Crooked Run, Happy Creek, Long Branch, Manassas Run, Stephens Run, West Run, and Willow Brook segments.

The bacteria TMDLs for the impaired segments were developed not to exceed the *E. coli* monthly geometric mean criterion, 126 *E. coli* cfu/100mL. The modeling was conducted with fecal coliform inputs, and then a translator equation provided by VADEQ was used to convert the output to *E. coli* concentrations.

1.2.3. **General Standard (9 VAC 25-260-20)**

The general standard for a water body in Virginia is stated as follows:

"A. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life.

Specific substances to be controlled include, but are not limited to: floating debris, oil scum, and other floating materials; toxic substances (including those which bioaccumulate); substances that produce color, tastes, turbidity, odors, or settle to form sludge deposits; and substances which nourish undesirable or nuisance aquatic plant life. Effluents which tend to raise the temperature of the receiving water will also be controlled." (SWCB, 2011)

The biological monitoring program in Virginia that is used to evaluate compliance with the above standard is administered by the Virginia Department of Environmental Quality (DEQ). Evaluations of monitoring data from this program focus on the benthic (bottom-dwelling) macro (large enough to see) invertebrates (insects, mollusks, crustaceans, and annelid worms) and are used to determine whether or not a stream segment has a benthic impairment. Changes in water quality generally result in alterations to the quantity and diversity of the benthic organisms that live in streams and other water bodies. Besides being the major intermediate constituent of the aquatic food chain, benthic macro-invertebrates are "living recorders" of past and present water quality conditions. This is due to their relative immobility and their variable resistance to the diverse contaminants that are introduced into streams. The community structure of these organisms provides the basis for the biological analysis of water quality. Both qualitative and semi-quantitative biological monitoring have been conducted by DEQ since the early

1970's. The U.S. Environmental Protection Agency's (USEPA) Rapid Bioassessment Protocol (RBP) II was employed beginning in the fall of 1990 to utilize standardized and repeatable assessment methodology (Barbour et al., 1999). For any single sample, the RBP II produces water quality ratings of "non-impaired," "slightly impaired," "moderately impaired," or "severely impaired." In Virginia, benthic samples are typically collected and analyzed twice a year in the spring and in the fall.

The RBP II procedure evaluates the benthic macro-invertebrate community by comparing ambient monitoring "network" stations to "reference" sites. A reference site is one that has been determined to be representative of a natural, non-impaired water body. The RBP II evaluation also accounts for the natural variation noted in streams in different eco-regions. One additional product of the RBP II evaluation is a habitat assessment. This is a stand-alone assessment that describes bank condition and other stream and riparian corridor characteristics and serves as a measure of habitat suitability for the benthic community.

Beginning in 2006, DEQ modified their bioassessment procedures. While the RBP II protocols were still followed for individual metrics, a new index, the Virginia Stream Condition Index (VSCI), was developed based on comparison of observed data to a set of reference conditions, rather than with data from a reference station (VADEQ, 2006). The new index was also calculated for all previous samples in order to better assess trends over time.

Determination of the degree of support for the aquatic life designated use is based on biological monitoring data and the best professional judgment of the regional biologist, relying primarily on the most recent data collected during the current 6-year assessment period. In Virginia, any stream segment with a benthic score less than the impairment threshold is placed on the state's 303(d) list of impaired streams (VADEQ, 2012).

Chapter 2: Watershed Characterization

2.1. *Selection of Sub-watersheds*

To account for the spatial distribution of pollutant sources, the Shenandoah River tributaries watersheds were subdivided into 31 sub-watersheds as shown in Figure 2.1. The impaired Shenandoah River tributaries, and their corresponding sub-watersheds, are shown in Table 2.1. The stream network used to help define the sub-watersheds was obtained from the National Hydrography Dataset. Sub-watersheds were delineated based on a number of factors: continuity of the stream network, similarity of land use distribution, and monitoring station locations. It is preferable to have a sub-watershed outlet at or near monitoring station locations in order to calibrate the model chosen for this study (to be discussed in Chapter 6); the monitoring stations used in modeling are also shown in Figure 2.1.

Table 2.1. Study streams and corresponding sub-watersheds.

Stream Name	Corresponding Sub-watersheds
Crooked Run	1, 6, & 10-13
West Run	2-5
Stephens Run	7-9
Willow Brook	14-16
Borden Marsh Run	17-19
Long Branch	20-21
Happy Creek	22-28
Manassas Run	29-31

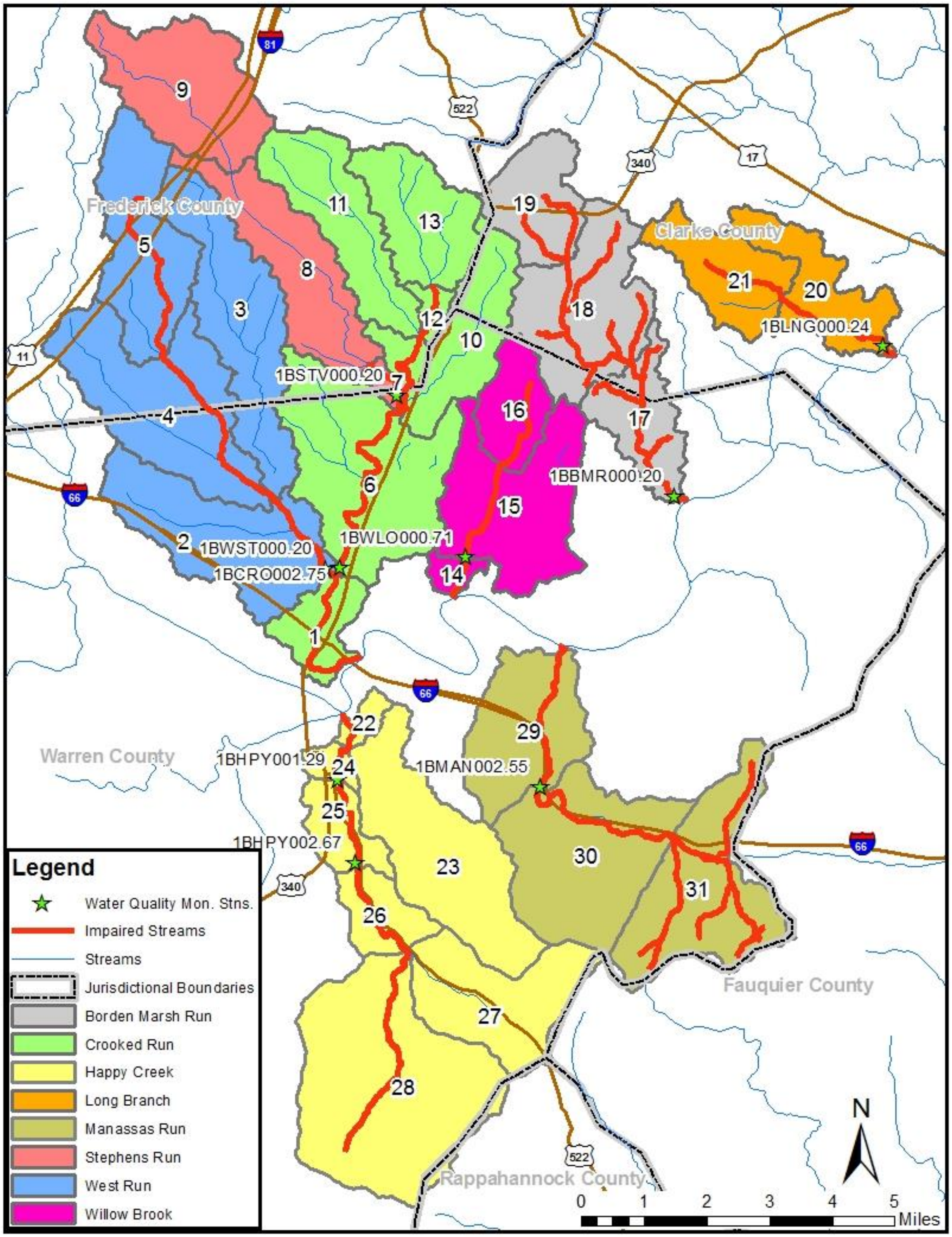

Figure 2.1. Sub-watersheds and water quality modeling stations used for modeling Shenandoah River tributaries watersheds.

2.2. *Water Resources, Ecoregion, Soils, and Climate*

2.2.1. Water Resources

The Borden Marsh Run watershed is part of the Upper Shenandoah River basin (USGS HUC 02070007) and comprises part of state hydrologic unit B55 (National Watershed Boundary Dataset PS81). The Borden Marsh Run watershed is located in Clarke, Warren, and Frederick Counties. Borden Marsh Run generally flows south and discharges into the Shenandoah River.

The Crooked Run watershed, including its tributaries West Run and Stephens Run, comprises the Crooked Run basin (USGS HUC 02070007) and comprises state hydrologic unit B56 (National Watershed Boundary Dataset PS79). The Crooked Run watershed is located in Warren, Frederick, and Clarke Counties. Crooked Run generally flows southwest and discharges into the Shenandoah River.

The Happy Creek watershed is part of the Lower South Fork Shenandoah River basin (USGS HUC 02070005) and comprises part of state hydrologic unit B41 (National Watershed Boundary Dataset PS48). Happy Creek is located in Warren County and includes a majority of the Town of Front Royal. Happy Creek flows north and discharges into South Fork Shenandoah River, which discharges into the Shenandoah River.

The Long Branch watershed is part of the Shenandoah River/Spout Run basin (USGS HUC 02070007) and comprises part of state hydrologic unit B57 (National Watershed Boundary Dataset PS82). The Long Branch watershed is located in Clarke County. Long Branch generally flows south and discharges into the Shenandoah River.

The Manassas Run watershed is part of the Upper Shenandoah River basin (USGS HUC 02070007) and comprises part of state hydrologic unit B55 (National Watershed Boundary Dataset PS80). The Manassas Run watershed is located in Warren County. Manassas Run generally flows north and discharges into the Shenandoah River.

The Willow Brook watershed is part of the Upper Shenandoah River (USGS HUC 02070007) and comprises part of state hydrologic unit B55 (National Watershed Boundary Dataset PS80). The Willow Brook watershed is located in in Warren and Clarke Counties. Willow Brook generally flows south and discharges into the Shenandoah River.

All the streams in this study ultimately flow to the Shenandoah River, which is a tributary of the Potomac River, which flows into the Chesapeake Bay.

2.2.2. **Ecoregion**

The Shenandoah River tributaries watersheds are located within multiple ecoregions. The Happy Creek and Manassas Run watersheds are mostly located within the Northern Igneous Ridges (66a) sub-division of the Blue Ridge (66) ecoregion and the Northern Limestone/Dolomite Valleys (67a) sub-division of the Ridge and Valley (67) ecoregion. Also present to a lesser degree are the Piedmont Uplands (64c) subdivision of the Northern Piedmont ecoregion and the Northern Sedimentary and Metasedimentary Ridges (66b) subdivision of the Blue Ridge (66) ecoregion. Ecoregion 66a consists of pronounced ridges separated by high gaps and coves. Mountain flanks are steep and well dissected. Crestal elevations tend to rise southward. Ecoregion 67a is a lowland characterized by broad, level to undulating, fertile valleys that are extensively farmed. The Great Valley, the Shenandoah Valley, and the Nittany Valley all occur in Ecoregion 67a. Sinkholes, underground streams, and other karst features have developed on the underlying limestone/dolomite, and as a result, the drainage density is low. Where streams occur, they tend to have gentle gradients, plentiful year around flow, and distinctive fish assemblages (Woods et al., 1999).

Borden Marsh Run, Long Branch, and Willow Brook are located almost entirely within the Northern Limestone/Dolomite Valleys (67a) sub-division of the Ridge and Valley (67) ecoregion.

The Crooked Run, Stephens Run, and West Run watersheds are located within the Northern Shale Valleys (67b) sub-division of the Ridge and Valley (67) ecoregion and the Northern Limestone/Dolomite Valleys (67a) sub-division of the Ridge and Valley (67) ecoregion. The Northern Shale Valleys (67b) sub-division is characterized by rolling valleys and low hills and is underlain mostly by shale, siltstone, and fine-grained sandstone. The underlying rocks are not as permeable as the limestone of Ecoregion 67, so surface streams are larger and drainage density is higher than in limestone areas. There is more soil erosion in Ecoregion 67b than in the Northern Limestone/Dolomite Valleys (67a). As a result, the stream turbidity can be comparatively high and the stream habitat relatively impaired (Woods et al., 1999).

2.2.3. **Soils**

The State Soil Geographic Data (STATSGO) soils data were used for the purpose of characterizing the soils in the study watersheds. Hydrologic soil groups were primarily considered for this characterization, and describe soil texture in terms of potential for surface runoff and infiltration rates. For example, soils in hydrologic group "A" pass a larger proportion of rainfall through to ground water than soils in hydrologic group "B." Conversely, soils in hydrologic group "D" inhibit infiltration such that a large proportion of rainfall contributes to surface runoff and therefore a more direct path to stream channels. These processes have consequences for bacteria residing on the land surface in terms of the potential bacteria loads transported to streams during storm events.

Comprising 63% of the Borden Marsh Run watershed area, the Hagerstown-Duffield-Clarksburg soil map unit is dominant, and is characteristically in hydrologic group B. The dominant soil map units in the Crooked Run watershed include Weikert-Berks (50%) and Lowell-Frederick-Chilhowie-Carbo (46%), which are characteristically hydrologic group B and C respectively. The Weikert-Berks soil map unit, which is characterized by hydrologic group C, dominates the Happy Creek watershed (74%) and the West Run watershed (80%). The dominant soil map units in the Manassas Run watershed include Myersville-Catoctin (42%) and Hayesville (24%), which are characteristically hydrologic group C and B respectively. The dominant soil map units in the Stephens Run watershed include Weikert-Berks (47%) and Lowell-Frederick-Chilhowie-Carbo (42%), which are characteristically hydrologic group C and B respectively. Comprising 94% of the Willow Brook watershed area, Hagerstown-Duffield-Clarksburg soil map unit is dominant, and is characteristically in hydrologic group B.

2.2.4. **Climate**

The climate of the study watersheds was characterized based on the meteorological observations acquired from the Front Royal National Climatic Data Center station (443229) located in the center of the watershed at Front Royal, Virginia approximately 3.35 miles south southeast from the Happy Creek confluence with the South Fork Shenandoah River. Average annual precipitation at this station is 40.9 inches; while the average annual daily temperature is 54.0°F. The highest average daily temperature of 87°F occurs in July while the lowest average daily temperature of 3°F occurs in January, as obtained from climate normal data for the period 1981-2010 (University of Washington, 2014).

2.3. *Bacteria Land Use*

To develop the bacteria TMDL, the 2012 National Agricultural Statistics Service (NASS) land use data, which includes National Land Cover Database (NLCD) 2006 land use data, were used to characterize land use in the watershed. A “Transportation” land use was added to the dataset by defining a 35-foot buffer around major roadways (highways) center lines and replacing existing land use with the buffer where applicable. Stakeholder input and aerial photos were used to verify land use characterization, and were used to adjust cropland area estimates as necessary. The land cover categories in the Shenandoah River and tributaries watersheds were grouped into eight major categories based on similarities in hydrologic features and waste application/production practices (Table 2.2). The land use categories were assigned pervious and impervious percentages for use in the watershed models. Land uses for the Shenandoah River tributaries watersheds are presented graphically in Figure 2.2 and tabulated in Table 2.3.

Table 2.2. NASS, NLCD, and land use aggregation.

TMDL Land Use Categories	**Pervious/Impervious (Percentage)**	**NASS Land Use Categories (Class No.)**
Cropland	Pervious (100%)	Corn (1) Sorghum (4) Soybeans (5) Crop (12) Barley (21) Winter Wheat (24) Winter Wheat/Soybeans (26) Rye (27) Oats (28) Millet (29) Potatoes (43) Other Crops (44) Misc. Fruit & Veg. (47) Fallow/Idle Cropland (61) Peaches (67) Apples (68) Grapes (69) Christmas Trees (70) Misc. Fruits & Nuts (71) Greens (219) Dbl. Crop Winter Wheat/Corn (225) Dbl. Crop Barley/Sorgum (235) Dbl. Crop Barley/Corn (237) Dbl. Crop Barley/Soybeans (254)
Hayland	Pervious (100%)	Other Hays (37)
Pasture	Pervious (100%)	Alfalfa (36) Seed/Sod Grass (59) Grass/Pasture (62)
Low Intensity Development (LID)	Pervious (90%); Impervious (10%) Pervious (65%); Impervious (35%) Pervious (35%); Impervious (65%)	NLCD - Developed/Open Space (121) NLCD - Developed/Low Intensity (122) NLCD - Developed/Medium Intensity (123)
High Intensity Development (HID)	Pervious (10%); Impervious (90%)	NLCD - Developed/High Intensity (124)
Forest	Pervious (100%)	NLCD – Barren (131) NLCD - Deciduous Forest (141) NLCD - Evergreen Forest (142) NLCD - Mixed Forest (143) NLCD – Shrubland (152) NLCD – Grassland Herbaceous (171) NLCD – Woody Wetlands (190) NLCD – Herbaceous Wetlands (195)
Water	Pervious (100%)	NLCD - Open Water (111)
Transportation	Pervious (10%); Impervious (90%)	N/A – 35’ Buffer of Maj. Routes

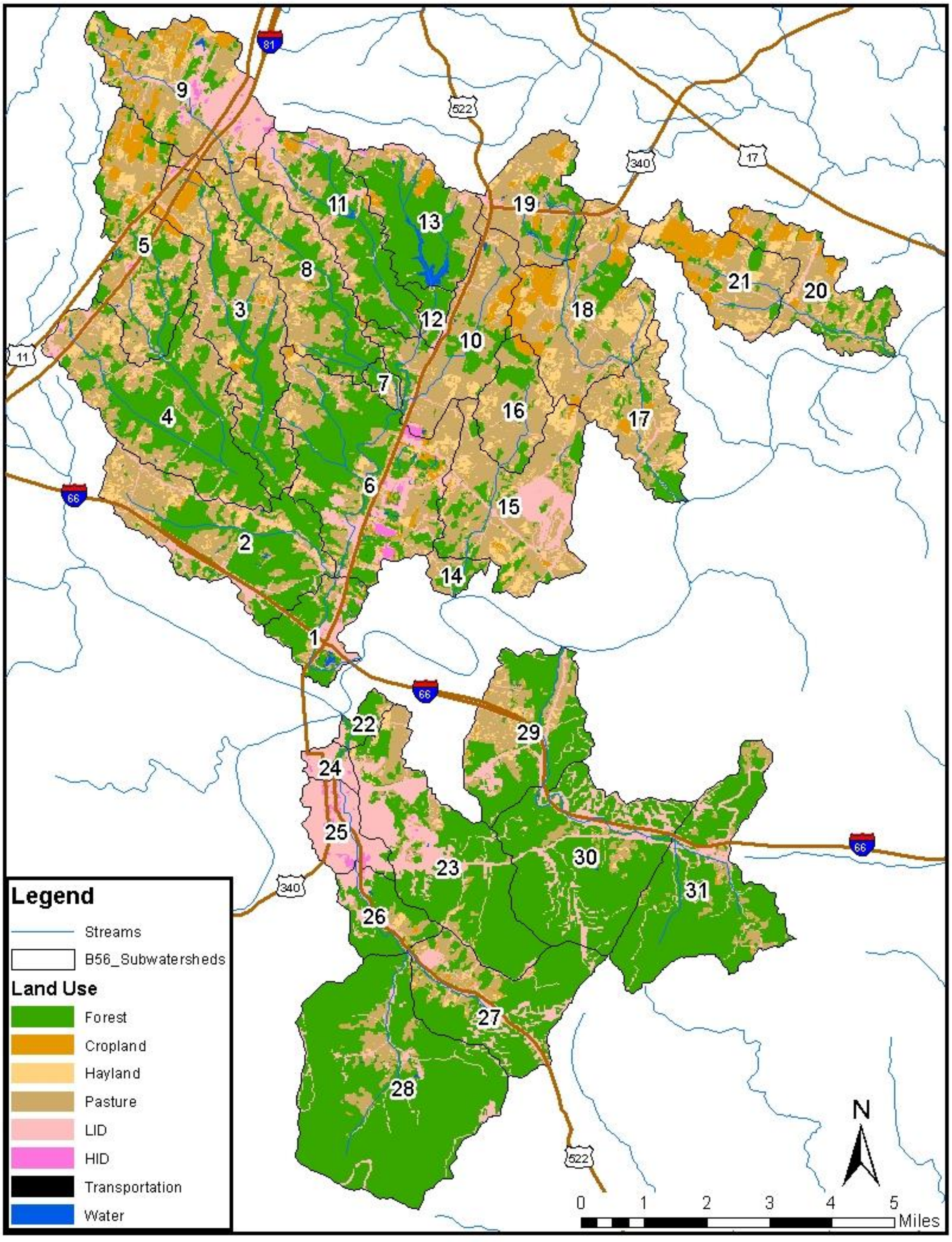

Figure 2.2. Land use in the Shenandoah River tributaries watersheds.

Table 2.3. Land use areas in the Shenandoah River tributaries watersheds (acres).

Sub-watershed	Forest	Cropland	Pasture	Hayland	LID	HID	Water	Trans	Total
1	527	17	120	21	268	10	22	26	1,011
2	1,371	21	1,039	295	393	0	10	38	3,167
3	1,222	180	1,268	314	170	2	3	13	3,172
4	1,975	14	1,196	247	244	5	10	11	3,702
5	760	294	1,022	325	217	4	13	23	2,658
6	1,714	142	1,327	322	546	87	24	22	4,184
7	91	1	63	13	15	0	1	0	184
8	960	64	1,083	306	135	1	4	4	2,557
9	309	330	1,057	286	785	49	13	25	2,854
10	406	106	1,334	169	196	21	9	29	2,270
11	1,153	76	548	112	345	8	19	0	2,261
12	196	2	53	3	14	0	3	0	271
13	1,225	85	376	48	115	6	106	0	1,961
14	126	1	122	14	17	0	0	0	280
15	408	55	1,604	418	528	0	1	0	3,014
16	247	42	689	142	12	0	0	0	1,132
17	257	76	795	306	58	0	1	0	1,493
18	354	444	1,439	530	176	0	3	5	2,951
19	271	116	883	116	133	2	18	17	1,556
20	329	226	848	203	94	0	1	0	1,701
21	140	386	750	309	43	0	1	0	1,629
22	194	0	28	14	36	0	1	0	273
23	2,058	8	454	90	921	4	3	0	3,538
24	26	0	12	1	214	15	0	8	276
25	26	0	14	0	686	119	0	24	869
26	561	9	97	24	221	7	2	13	934
27	1,584	33	390	66	467	0	2	26	2,568
28	4,969	11	382	20	303	0	3	0	5,688
29	1,299	19	625	104	377	0	4	23	2,451
30	2,782	3	164	20	681	1	4	19	3,674
31	2,648	15	287	16	335	0	0	8	3,309
Total	**30,188**	**2,776**	**20,069**	**4,854**	**8,745**	**341**	**281**	**334**	**67,588**

2.4. ***Benthic Land Use***

Land use categories for the Happy Creek watershed were derived from the 2012 cropland data layer developed by the USDA National Agricultural Statistics Service (USDA-NASS, 2012). The NASS data are available online and were developed from USDA National Resources Inventory data in agricultural areas and supplemented with 2006 National Land Classification Data (NLCD) in non-agricultural areas. The Happy

Creek watershed is 14,145 acres in size. The main land use category in the watershed is forest, which comprises approximately 66.3% of the watershed, followed by 21.8% in developed land uses, and 11.8% in agricultural land uses. Broad categories of land use in the Happy Creek watershed are shown in Figure 2.3, with detailed categories given in Table 2.4.

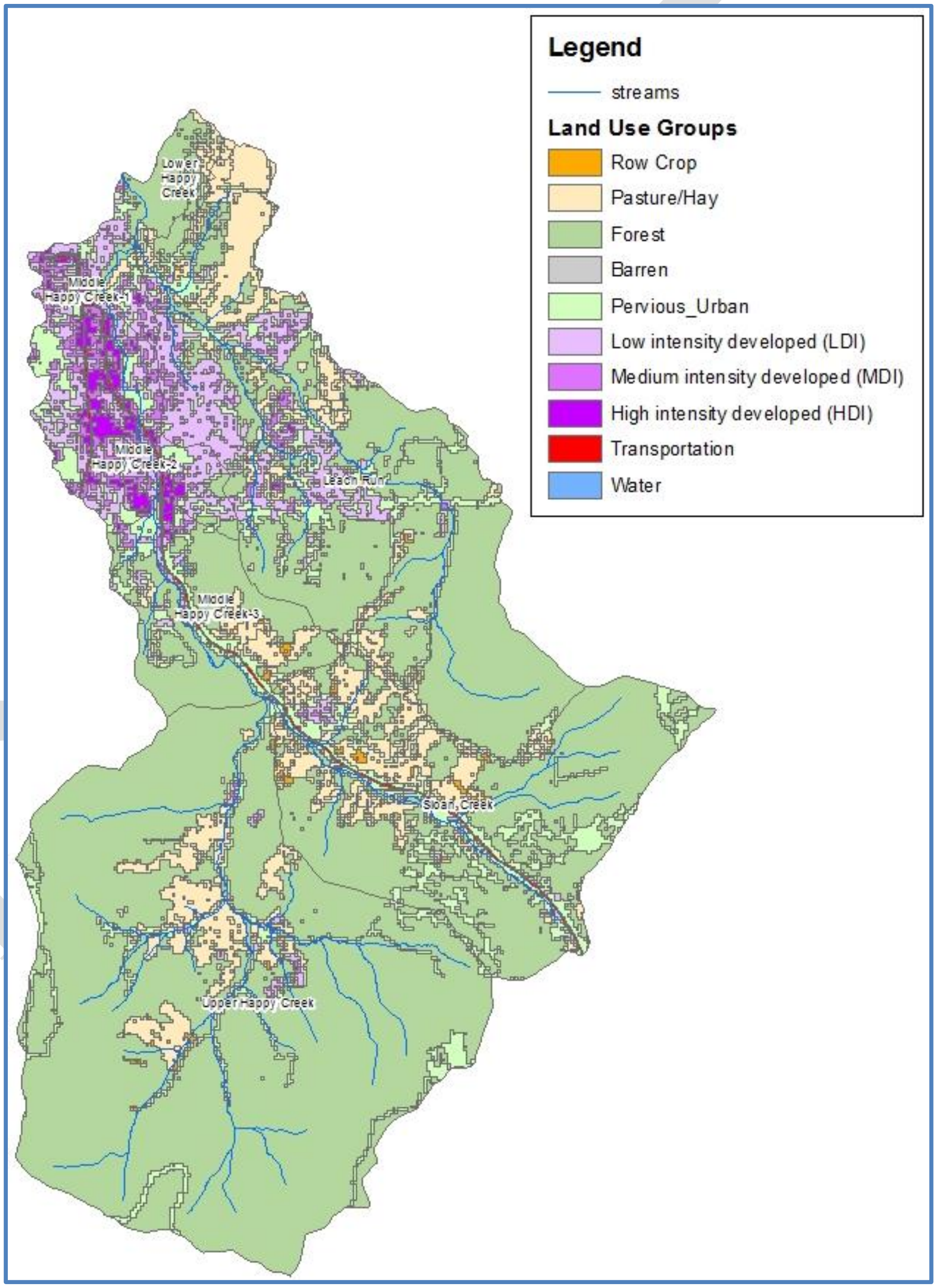

Figure 2.3. NASS Generalized Land Use in the Happy Creek Watershed

Table 2.4. NASS Land Use Summary in the Happy Creek watershed (acres)

NASS Code	NASS Land Use Class	Area (acres)
1	Corn	11.9
4	Sorghum	0.8
5	Soybeans	1.3
21	Barley	0.4
24	Winter Wheat	3.0
28	Oats	0.1
36	Alfalfa	2.3
37	Other Pasture/Hays	214.1
61	Fallow/Idle Cropland	3.3
62	Pasture/Grass	1,361.9
68	Apples	40.9
111	NLCD - Open Water	10.8
121	NLCD - Developed/Open Space	1,460.1
122	NLCD - Developed/Low Intensity	1,073.8
123	NLCD - Developed/Medium Intensit	328.2
124	NLCD - Developed/High Intensity	144.8
131	NLCD - Barren	0.5
141	NLCD - Deciduous Forest	9,259.0
142	NLCD - Evergreen Forest	137.8
143	NLCD - Mixed Forest	12.0
152	NLCD - Shrubland	0.2
171	NLCD - Grassland Herbaceous	5.9
190	NLCD - Woody Wetlands	1.3
237	Dbl. Crop Barley/Corn	0.4
999	Transportation	70.7
Total Area		**14,145.5**

2.5. ***Bacteria Monitoring Data***

VADEQ monitors water quality within the impaired Shenandoah River tributaries watersheds at eight stations that were used to evaluate and list the impaired streams. The locations of these stations were shown previously (Figure 2.1); a summary of the bacteria data, including violation rates of the appropriate single-sample criteria, is presented in Table 2.5

Table 2.5. VADEQ monitoring stations within the impaired Shenandoah River tributaries watersheds.

Station ID	Stream Name	Station Description	Indicator Organism Measured	Number of Samples	Violation Rate	Period of Record
1BBMR000.20	Borden Marsh Run	Off Rt. 642	*E. coli*	38	47.4%	2003 - 2013
1BCRO002.75	Crooked Run	Off Rt. 627	*E. coli*	78	19.2%	2005 - 2013
1BHPY001.29	Happy Creek	In park near Bing Crosby Stadium	*E. coli*	12	33.3%	2011 - 2012
1BLNG000.24	Long Branch	Near Rt. 622 Bridge	*E. coli*	52	34.6%	2004 – 2013
1BMAN002.55	Manassas Run	Near Rt. 647 Bridge	*E. coli*	20	15.0%	2012 - 2013
1BSTV000.20	Stephens Run	Near Rt. 639 Bridge	*E. coli*	76	13.2%	2003 - 2013
1BWST000.20	West Run	Near Rt. 609 Bridge	*E. coli*	64	18.8%	2005 – 2013
1BWLO000.71	Willow Brook	Near Rt. 658 Bridge	*E. coli*	32	37.5%	2004 – 2013

Seasonality of *E. coli* concentrations in the streams was evaluated by plotting the mean monthly *E. coli* concentrations observed at station 1BCRO002.75, the station on Crooked Run which has the most data available and best temporal distribution (Figure 2.4).

Mean monthly *E. coli* concentration was determined as the mean of all values in any given month for the period of record; there were between 5 and 9 samples available for every month. The observed bacteria record shows some seasonality, with higher average values observed in the spring from March through May.

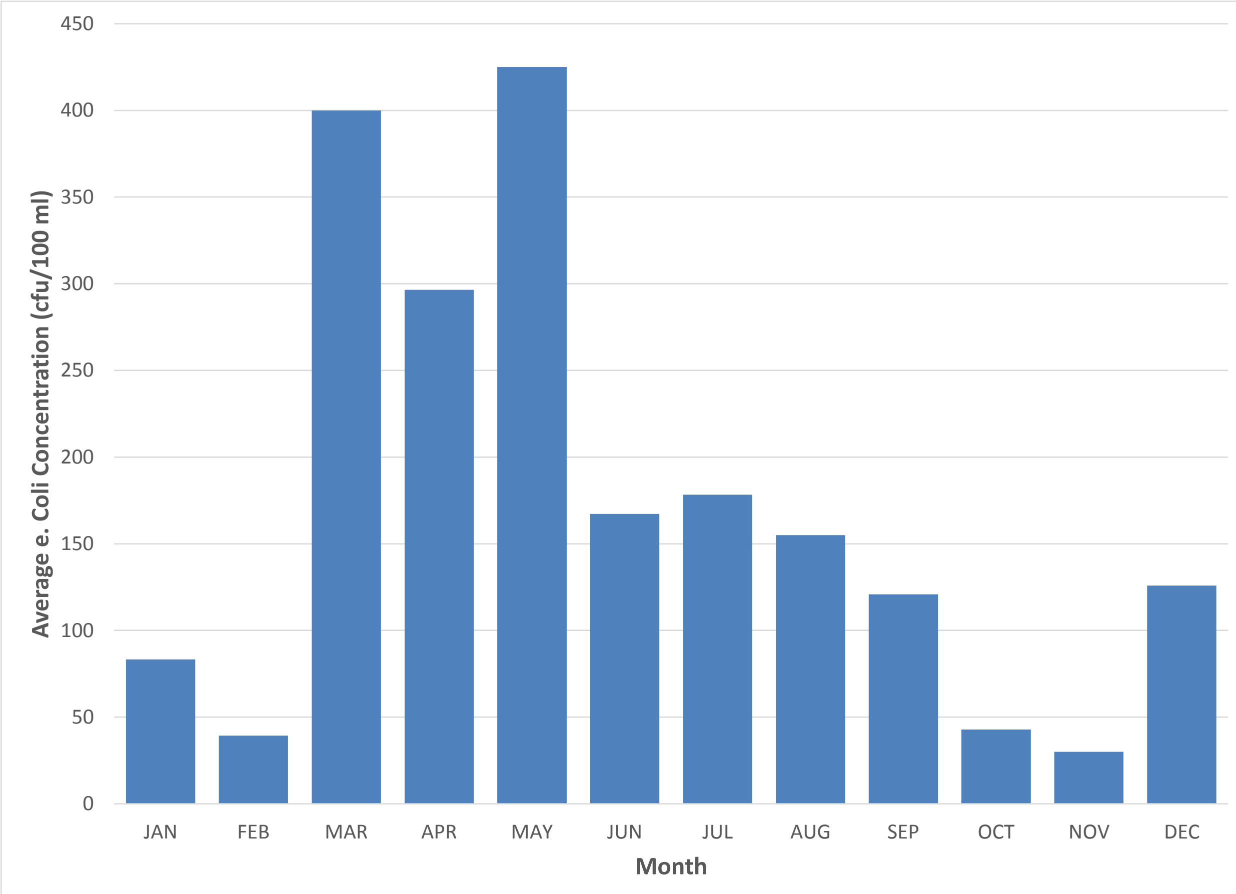

Figure 2.4. Average E. coli concentrations by month for station 1BCRO002.75.

2.6. *Biological Monitoring Data – Benthic Macro-invertebrates*

Biological monitoring consisted of sampling the benthic macro-invertebrate community along with corresponding habitat assessments. The data for the bioassessments in Happy Creek were based on DEQ biological monitoring at two DEQ monitoring sites, together with two sites monitored by the Save Our Streams program (1BHPY-1-SOS and 1BHPY-2-SOS), together with additional ambient monitoring data from four Friends of the Shenandoah River (FOSR) sites on Happy Creek (1BHPY-FW09-FOSR, 1BHPY-FW10-FOSR, 1BHPY-FW11-FOSR, and 1BHPY-FW27-FOSR) and one on Leach Run (1BHPY-FW29-FOSR), and a DEQ trend station (1BHPY003.06). The locations of the all biological and ambient monitoring stations in the Happy Creek watershed are shown in Figure 2.5. The biological monitoring data was provided by the DEQ Valley Regional Office from the state's Environmental Data Analysis System (EDAS) database.

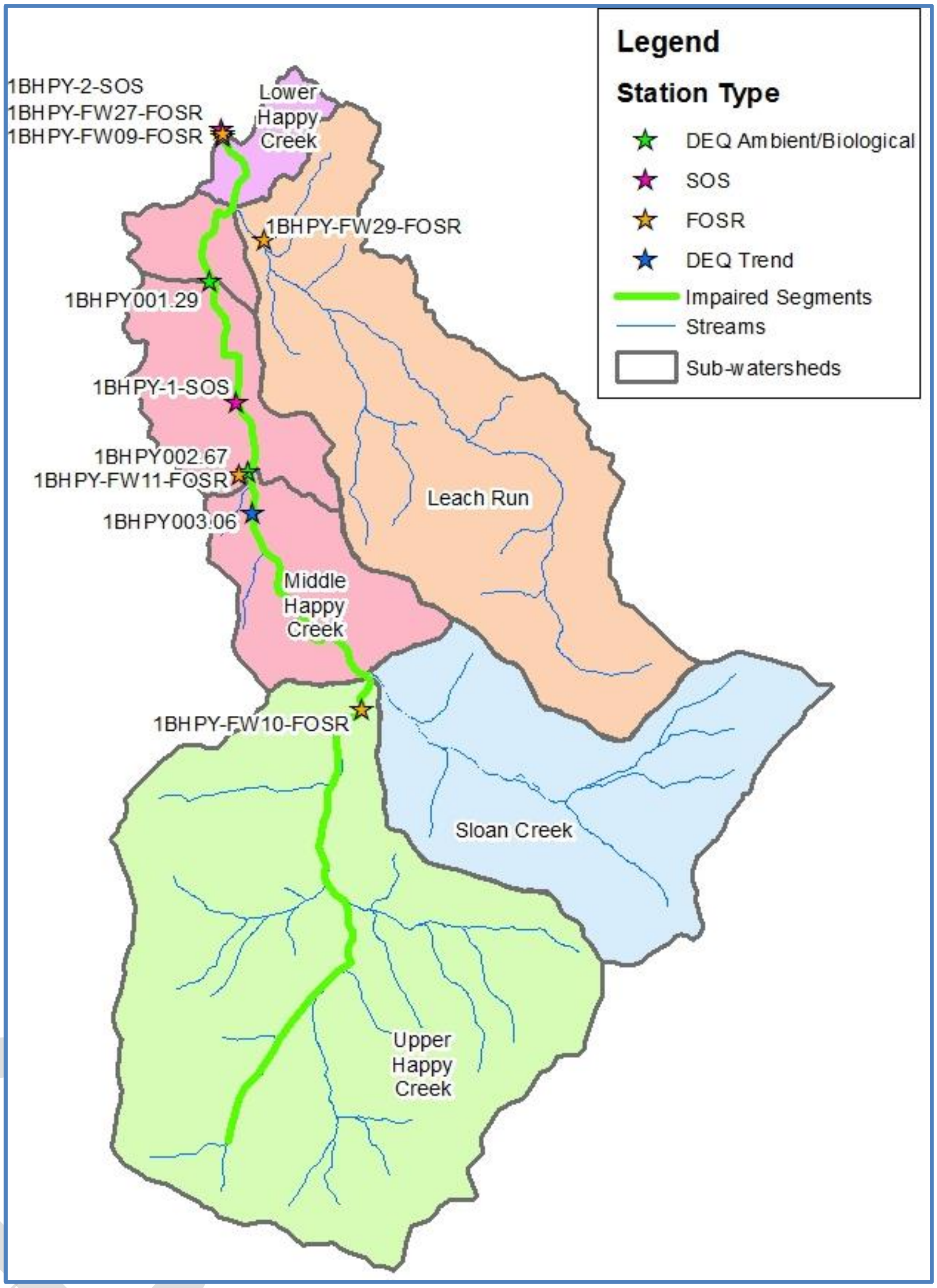

Figure 2.5. DEQ, SOS, and FOSR monitoring stations in the Happy Creek watershed

DEQ biological samples were collected from the best available habitat using riffle or multi-habitat methods. The samples were then preserved and sub-sorted, and then the organisms were identified to the family and/or genus taxonomic level. A full listing of the benthic macro-invertebrate taxa inventory or distribution within each DEQ biological sample is given for Happy Creek in Table 2.6 for the downstream station 1BHPY001.29 and in Table 2.7 for the upstream station 1BHPY002.67.

Table 2.6. DEQ Taxa Inventory by Sample Date at 1BHPY001.29

FinalID	Functional Family Group	Tolerance Value	1BHPY001.29								
			05/14/04	10/08/04	05/06/06	10/30/06	04/09/08	10/21/10	03/28/12	10/16/12	05/21/13
Capniidae	Shredder	1						3			
Perlidae	Predator	1	1		2		1	1			1
Stenelmis	Scraper	1								5	
Baetis	Collector	2								2	3
Isonychia	Filterer	2								14	1
Isonychiidae	Filterer	2	3	2		3	1	8			
Nemouridae	Shredder	2	1		1		4				
Taeniopterygidae	Shredder	2						4			
Chimarra	Filterer	3							1	25	
Hydropsychidae	Filterer	3									14
Philopotamidae	Collector	3		1		1	4	14			
Simulium	Filterer	3							8	7	20
Tipulidae	Shredder	3			1		1	1			
Antocha	Collector	4								1	1
Baetidae	Collector	4	34								1
Elmidae	Scraper	4		1	1						
Ephemerellidae	Collector	4					2				
Heptageniidae	Scraper	4	1	14	1		1	11	1		
Psephenidae	Scraper	4	1	2			1	3			
Psephenus	Scraper	4								2	
Cambaridae	Shredder	5		2							
Tricladida	Collector	5								5	1
Ancylidae	Scraper	6			3			2	1	1	
Cheumatopsyche	Filterer	6								12	7
Gammaridae	Collector	6			3						
Simuliidae	Filterer	6	23		3	43		7			
Chironomidae (A)	Collector	6	37	2	63	1	25	23			
Hydropsychidae		6	2	6	1	30	6	20			
Corbiculidae	Filterer	8			3						
Lumbriculidae	Collector	8		9		26		3			
Naididae	Collector	8	1		88		50	4			
Physidae	Scraper	8			3	1				1	
Naididae		9							53		24
Lumbricidae	Collector	10			5			3			
Tubificidae	Collector	10	1	46	2						
Chironomidae (A)		(blank)							40	23	37
VSCI			47	42	32	34	40	63	23	65	35
Scraper/Filter-Collector Ratio			0.02	0.28	0.05	0.01	0.02	0.25	0.20	0.12	0.00
%Filterer-Collector			93.4%	69.8%	92.3%	69.8%	82.8%	58.7%	9.1%	67.3%	43.6%
%Haptobenthos			27.4%	27.9%	6.6%	70.8%	15.2%	53.2%	1.8%	0.9%	13.6%
%Shredders			0.9%	2.3%	1.1%	0.0%	5.1%	7.3%	0.0%	0.0%	0.0%

- Dominant 2 species in each sample.
A number of additional taxa were identified with only 1 organism in all samples.
VSCI: Optimal > 60; suboptimal < 50.

Table 2.7. DEQ Taxa Inventory by Sample Date at 1BHPY002.67

FinalID	Functional Family Group	Tolerance Value	1BHPY002.67							
			06/02/08	09/22/08	04/07/10	10/21/10	03/25/11	10/18/11	03/28/12	10/16/12
Epeorus	Scraper	0							2	
Acroneuria	Predator	1							3	
Capniidae	Shredder	1				16				3
Perlidae	Predator	1			1	1				
Amphinemura	Shredder	2							16	
Ephemerella	Collector	2							8	
Isonychia	Filterer	2								30
Isonychiidae	Filterer	2	3	7		5	1	14		
Nemouridae	Shredder	2			39		13			
Taeniopterygidae	Shredder	2				11		1		
Chimarra	Filterer	3							5	
Philopotamidae	Collector	3		16	1	18	1	7		
Simulium	Filterer	3							30	
Tipulidae	Shredder	3	1			1				
Acentrella	Collector	4							13	
Baetidae	Collector	4	40	3	8		1	1		
Elmidae	Scraper	4				2		1		
Ephemerellidae	Collector	4			6		2	2		
Heptageniidae	Scraper	4	3	30	5	13	2	20		
Pleuroceridae	Scraper	4						2		
Psephenidae	Scraper	4	3	5		3		6		
Psephenus	Scraper	4							3	1
Hydracarina (unknown)	Predator	5		2				1		
Ancylidae	Scraper	6		2			2	10		1
Cheumatopsyche	Filterer	6							2	42
Simuliidae	Filterer	6	10	10	44	15	25	2		
Chironomidae (A)	Collector	6	35	2	10	3	59	4		
Hydropsychidae		6	10	34	3	28	3	37		
Naididae	Collector	8	1	2						
Coenagrionidae	Predator	9						2		
Chironomidae (A)		(blank)							23	17
Maccaffertium		(blank)							1	13
Plecoptera (unknown)		(blank)	2							
VSCI			**47**	**65**	**59**	**69**	**39**	**65**	**64**	**46**
Scraper/Filter-Collector Ratio			0.07	0.93	0.07	0.44	0.04	1.30	0.08	0.03
%Filterer-Collector			82.6%	35.7%	58.0%	35.0%	80.9%	27.3%	53.6%	67.3%
%Haptobenthos			24.8%	85.2%	51.3%	69.2%	31.8%	79.1%	0.0%	1.8%
%Shredders			0.9%	0.0%	32.8%	23.9%	11.8%	0.9%	14.5%	2.7%

- Dominant 2 species in each sample.
A number of additional taxa were identified with only 1 organism in all samples
VSCI: Optimal > 60; suboptimal < 50.

In 2006, DEQ upgraded its biomonitoring and biological assessment methods to those currently recommended by USEPA Region 3 for the mid-Atlantic region. As part of this effort, a study was performed to assist the agency in moving from a paired-network/reference site approach based on the RBP II to a regional reference condition approach, and has led to the development of the Virginia Stream Condition Index (VSCI) for Virginia's non-coastal areas (Tetra Tech, 2003). This multi-metric index is based on

8 biomonitoring metrics, with a scoring range of 0-100, that include some different metrics than those used previously in the RBP II, but are based on the same taxa inventory. A maximum score of 100 represents the best benthic community sites. The current criteria define “non-impaired” sites as those with a VSCI of 60 or above, and those sites with VSCI scores below 60 as “impaired”. The VSCI individual metric scores, along with overall VSCI scores and interpreted ratings are shown for the downstream station (1BHPY001.29) in Table 2.8, while those for the upstream station (1BHPY002.67) are shown in Table 2.9.

Table 2.8. Biological Index (VSCI) Metrics and Scores at 1BHPY001.29 (downstream)

StationID	1BHPY001.29							
CollDate	05/14/04	10/08/04	05/06/06	10/30/06	04/09/08	10/21/10	03/28/12	10/16/12
VSCI Metric Scores								
Richness Score	54.5	50.0	72.7	36.4	63.6	77.3	36.4	72.7
EPT Score	63.6	36.4	36.4	27.3	63.6	72.7	18.2	72.7
%Ephem Score	58.5	30.4	0.9	4.6	6.6	29.9	7.4	28.2
%PT-H Score	7.9	3.3	4.7	2.6	25.5	56.7	2.6	68.9
%Scraper Score	3.7	38.3	9.6	1.8	3.9	28.4	3.5	15.9
%Chironomidae Score	65.1	97.7	65.2	99.1	74.7	78.9	63.6	79.1
%2Dom Score	47.7	43.7	24.0	45.0	35.0	87.5	22.3	81.5
%MFBI Score	71.4	33.2	43.1	53.6	50.7	74.3	28.7	97.4
IBI	47	42	32	34	40	63	23	65
VSCI Rating	**Stressed**	**Stressed**	**Severe Stress**	**Severe Stress**	**Severe Stress**	**Good**	**Severe Stress**	**Good**

- Primary biological effects.

Table 2.9. Biological Index (VSCI) Metrics and Scores at 1BHPY002.67 (upstream)

StationID	1BHPY002.67								
CollDate	06/02/08	09/22/08	04/07/10	04/07/10	10/21/10	03/25/11	10/18/11	03/28/12	10/16/12
VSCI Metric Scores									
Richness Score	50.0	59.1	50.0	50.0	59.1	50.0	68.2	68.2	36.4
EPT Score	54.5	54.5	72.7	72.7	63.6	63.6	63.6	81.8	36.4
%Ephem Score	68.8	56.7	31.7	26.0	25.1	8.9	54.9	35.6	65.3
%PT-H Score	7.7	41.5	60.0	99.1	100.0	35.8	20.4	63.8	7.7
%Scraper Score	10.7	64.0	5.6	8.1	29.8	7.0	68.7	8.8	3.5
%Chironomidae Score	67.9	98.3	79.6	91.6	97.4	46.4	96.4	79.1	84.5
%2Dom Score	45.1	64.1	60.3	43.7	87.7	34.2	69.6	74.9	49.9
%MFBI Score	73.3	77.9	77.0	84.5	89.4	68.0	77.5	100.0	83.2
IBI	47	65	55	59	69	39	65	**64**	**46**
VSCI Rating	**Stressed**	**Good**	**Stressed**	**Stressed**	**Good**	**Severe Stress**	**Good**	**Good**	**Stressed**

- Primary biological effects.

The dominant species of benthic macro-invertebrates at the downstream Happy Creek site are the pollutant-tolerant chironomidae (A) and Naididae (Table 2.6), while the dominant species at the upstream site (Table 2.7) include a greater mix of pollutant-sensitive and pollutant-tolerant species. The primary biological effects at both sites in Happy Creek are the low scores for the sensitive members of the plecoptera and tricoptera families and the scraper functional group (Table 2.8 and Table 2.9).

Since 2007, the Northern Shenandoah Tributaries chapter of the Izaac Walton League's Save Our Streams program has also conducted biological monitoring at two locations in Happy Creek shown previously in Figure 2.5.Specific metrics used as the basis for the SOS multi-metric scores are given in Table 2.10.

Table 2.10. Save Our Streams (SOS) Multi-Metric Metrics and Scores on Happy Creek

Monitoring Site	1BHPY-1-SOS					1BHPY-2-SOS						
Sampling Date	06/23/07	12/21/07	03/15/08	08/10/08	11/02/08	05/01/07	09/20/07	10/12/08	09/06/09	03/04/12	05/28/12	06/24/12
Metric 1 - Percent Mayflies, Stoneflies, and Most Caddisflies	26.8	40.5	25.6	36.0	34.3	51.9	39.8	34.1	23.0	58.2	13.8	33.8
Metric 2 - Percent Common Netspinners	42.3	53.4	38.7	34.6	53.1	36.1	50.9	43.8	31.1	4.7	21.8	19.9
Metric 3 - Percent Lunged Snails	0.5	3.3	1.3	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0
Metric 4 - Percent Beetles	2.3	0.2	1.3	0.5	2.8	0.0	0.0	2.7	2.9	0.0	13.4	13.6
Metric 5 - Percent Tolerant	27.7	4.9	34.5	28.4	8.7	11.5	7.4	18.6	39.7	35.9	33.2	15.1
Metric 6 - Percent Non-Insect	6.1	5.3	5.9	5.2	7.9	1.0	0.7	1.9	2.9	0.0	19.5	14.3
Multi Metric Score	5	6	5	8	7	8	8	8	7	10	8	10
Total Organisms	213	819	238	211	254	208	269	258	209	256	298	272
Sample Season	Summer	Winter	Spring	Summer	Fall	Spring	Fall	Fall	Fall	Winter	Spring	Summer
Ecological Conditions (Acceptable/Unacceptable)	U	U	U	G	U	G	G	G	U	A	A	A

A = Acceptable; **G** = Gray Zone; **U** = Unacceptable.

= Primary negative impacts on the Ecological Conditions.

A graph of individual sample VSCI and SOS multi-metric scores for Happy Creek is shown in Figure 2.6, with VSCI scores on the left axis and the SOS scores shown on the right axis. The two axes were approximately aligned with the respective impaired/non-impaired and non-acceptable/acceptable thresholds of the two scoring systems.

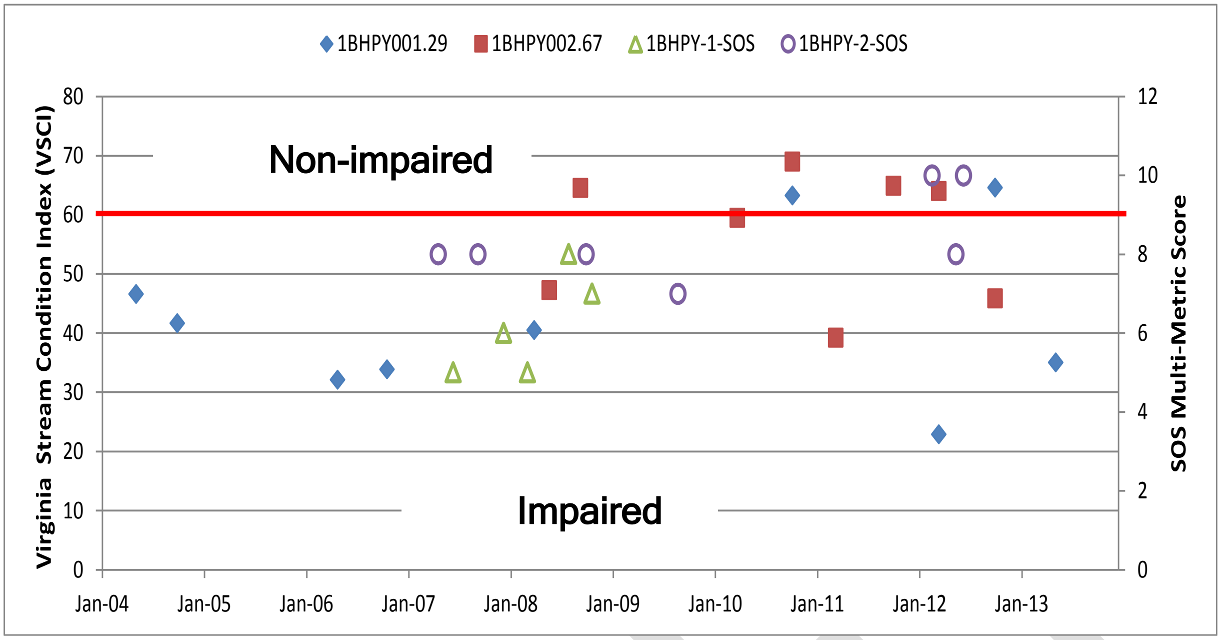

Figure 2.6. VSCI and SOS Multi-metric Scores for Happy Creek

2.7. *Biological Monitoring Data – Habitat*

A qualitative analysis of various habitat parameters was conducted in conjunction with each benthic macro-invertebrate sampling event. Habitat data collected as part of the biological monitoring were obtained from DEQ, also through the EDAS database. For each evaluation, ten metrics are scored on a 0-20 basis using EPA rapid biosassessment protocols (Barbour et al., 1999), with scores of 0-5 rated as “poor”; scores of 6-10 as “marginal”; scores of 11-15 as “sub-optimal”; and scores of 16-20 rated as “optimal”, with minor variations for those metrics scored separately for each stream bank. The maximum 10-metric total habitat score is 200; scores <120 are considered sub-optimal, and those >150 as optimal. The 10 metrics evaluated vary based on whether the best available habitat was dominated by riffle or multi-habitat (snags, leaf packs). The former is considered “high gradient” and the latter “low gradient.”

The habitat assessment data for Happy Creek are shown in Table 2.11 for the downstream site (1BHPY001.29) and in Table 2.12 for the upstream site (1BHPY002.67). The “riparian vegetative zone width” and “channel alteration” metrics have often received “poor” scores at the downstream site, while “riparian vegetative zone width” and “bank stability” were typically poorer at the upstream site. While a slight improvement can be seen in total habitat scores at the downstream site since 2004, scores are still less than optimal, while the majority of the scores at the upstream site have fairly consistently scored in the “optimal” range.

Table 2.11. Habitat Metric Scores for 1BHPY001.29 (downstream)

StationID	1BHPY001.29								
CollDate	05/14/04	10/08/04	05/09/06	10/30/06	04/09/08	10/21/10	03/28/12	10/16/12	05/21/13
Channel Alteration	4	11	9	9	12	13	15	6	7
Bank Stability[1]	11	9	12	11	10	11	12	14	15
Vegetative Protection[1]	11	9	13	11	8	10	11	16	16
Embeddedness	15	10	16	14	11	12	17	14	16
Channel Flow Status	18	16	16	18	16	13	18	16	18
Frequency of riffles (or bends)	3	14	11	14	17	15	16	12	13
Riparian Vegetative Zone Width[1]	4	7	4	2	5	4	5	6	4
Sediment Deposition	6	8	16	16	13	15	14	13	14
Epifaunal Substrate / Available Cover	18	11	18	18	14	13	18	16	17
Velocity / Depth Regime	16	16	13	16	15	18	16	14	16
10-Metric Total Habitat Score[2]	**106**	**111**	**128**	**129**	**121**	**124**	**142**	**127**	**136**

- Marginal or Poor habitat metric rating.

[1] Metric is the sum of scores for both the left and right banks.

[2] Total Habitat Score: optimal > 150; suboptimal < 120.

* Substitute metrics used under "Low Gradient" conditions.

Table 2.12. Habitat Metric Scores for 1BHPY002.67 (upstream)

StationID	1BHPY002.67							
CollDate	06/02/08	09/22/08	04/07/10	10/21/10	03/25/11	10/18/11	03/28/12	10/16/12
Channel Alteration	16	15	15	15	15	15	15	16
Bank Stability[1]	8	15	16	16	9	8	8	10
Vegetative Protection[1]	18	16	16	16	16	18	17	18
Embeddedness	17	18	17	14	19	14	18	14
Channel Flow Status	18	16	18	11	18	15	17	18
Frequency of riffles (or bends)	17	16	18	17	18	16	16	17
Riparian Vegetative Zone Width[1]	6	6	16	7	8	10	9	10
Sediment Deposition	15	15	15	15	18	14	16	17
Epifaunal Substrate / Available Cover	17	18	17	18	18	18	17	18
Velocity / Depth Regime	18	16	18	18	17	17	18	15
10-Metric Total Habitat Score[2]	**150**	**151**	**166**	**147**	**156**	**145**	**151**	**153**

- Marginal or Poor habitat metric rating.

[1] Metric is the sum of scores for both the left and right banks.

[2] Total Habitat Score: optimal > 150; suboptimal < 120.

* Substitute metrics used under "Low Gradient" conditions.

2.8. *Water Quality Data*

2.8.1. DEQ Ambient Monitoring Data

Ambient bi-monthly monitoring has been performed on the Happy Creek impaired segments at station 1BHPY001.29 since August 2001. Plots of monthly ambient water quality monitoring parameters are shown in the following figures for available data from

August 2001 through November 2012. Where applicable, minimum and/or maximum water quality standards, minimum detection limits (MDL), and sample analysis caps are indicated on the plots. Field physical parameters include water temperature, DO, and pH Figure 2.7 - Figure 2.9**Error! Reference source not found.**). Chemical parameters include: total N (shown on 2 separate graphs for 2001-2003 and 2011-2011, Figure 2.10 and Figure 2.11); total P (shown on 2 separate graphs for 2001-2003 and 2011-2011, Figure 2.12 and Figure 2.13); and ammonia (no samples above the minimum detection limit – data not shown). Conductivity, hardness, suspended solids, and chlorophyll were only collected from 2001-2003 (Figure 2.14 to Figure 2.17). Average nutrient concentrations at station 1BHPY001.29 are summarized in Table 2.13, along with two calculated ratios to assist in assessing nutrient influences in these watersheds.

Table 2.13. Nutrient Concentration Averages and Ratios

Period	TN		NO2+NO3-N		TKN		TP		TN:TP Ratio	TKN:TN Ratio
	No.	Ave.	No.	Ave.	No.	Ave.	No.	Ave.		
2001 - 2003	0		12	0.47	12	0.23	10	0.042	16.6	0.32
2011 - 2012	12	0.58	0		0		1	0.010	58.4	--

All stream segments within these watersheds are Class IV Mountainous Zones Waters (9VAC25-260-50). The upper portion of Happy Creek from Front Royal's raw water intake to its headwaters, including Sloan Creek is also classified as a Public Water Supply (PWS) (SWCB, 2011).

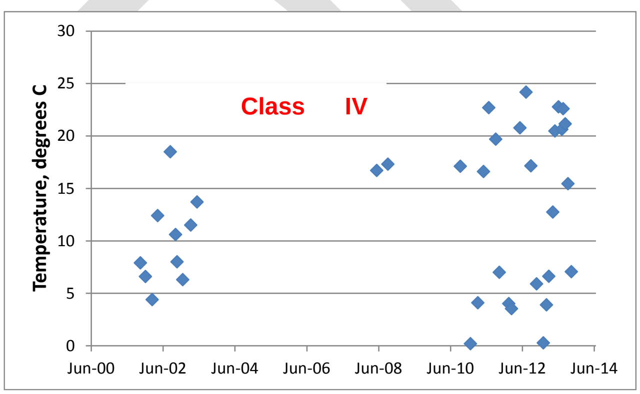

Figure 2.7. Field Temperature

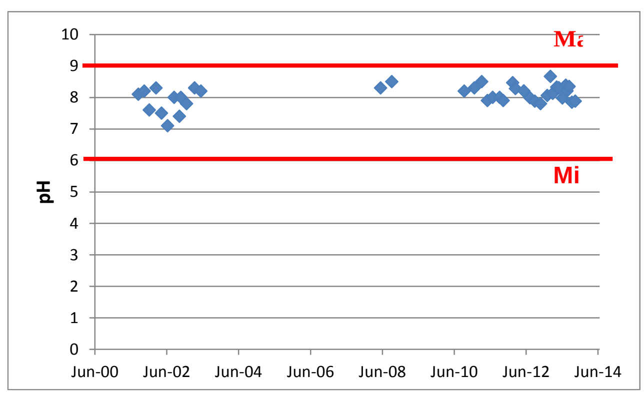

Figure 2.8. Field pH

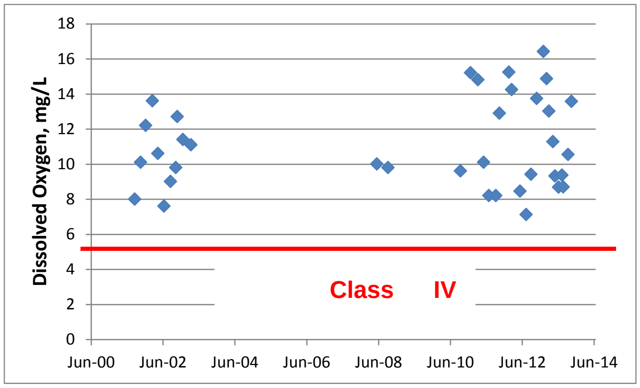

Figure 2.9. Field DO

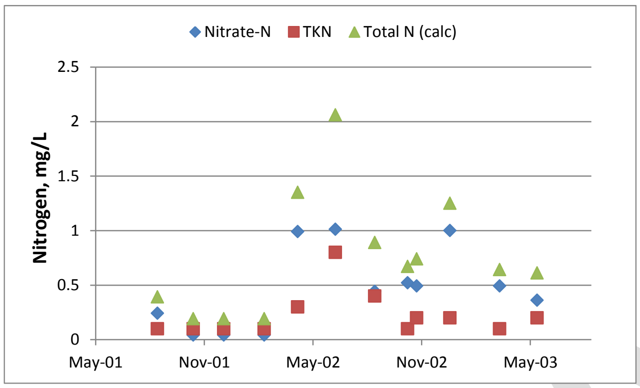

Figure 2.10. Nitrogen 2001-2003

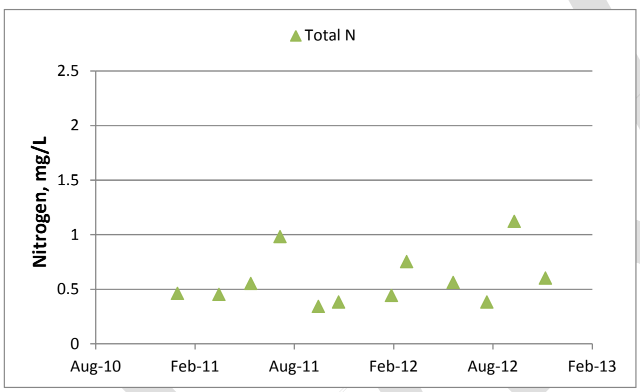

Figure 2.11. Nitrogen 2011-2012

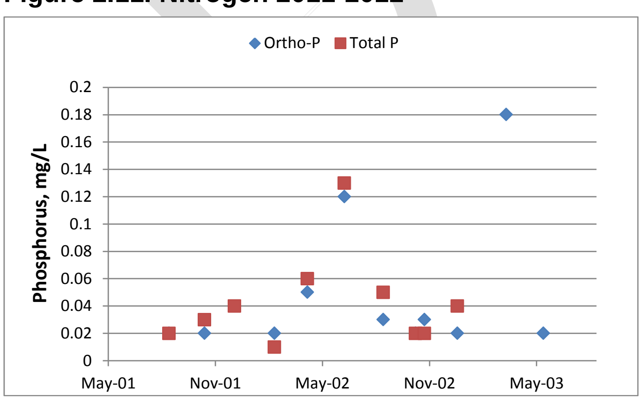

Figure 2.12. Phosphorus 2001-2003

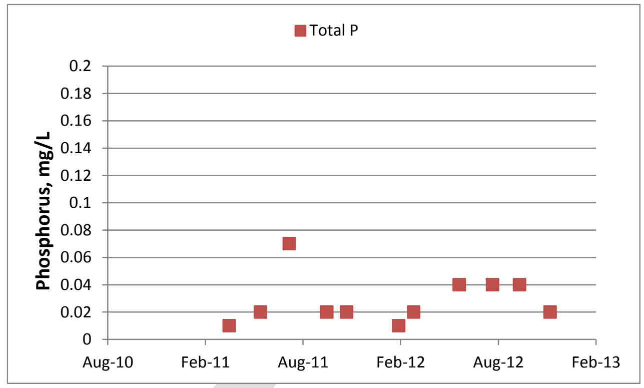

Figure 2.13. Phosphorus 2011-2012

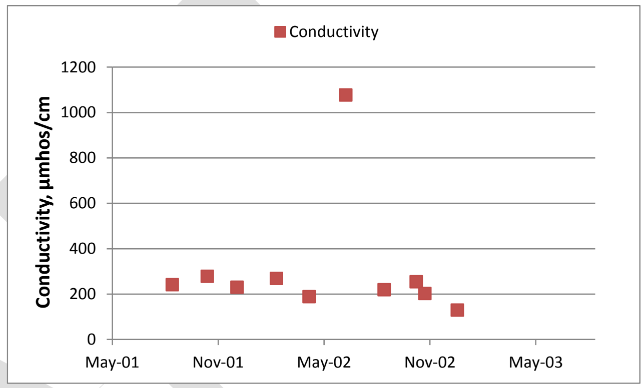

Figure 2.14. Conductivity 2001-2003

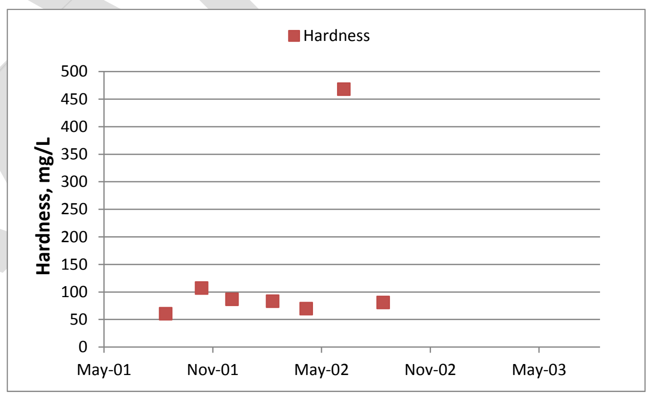

Figure 2.15. Hardness

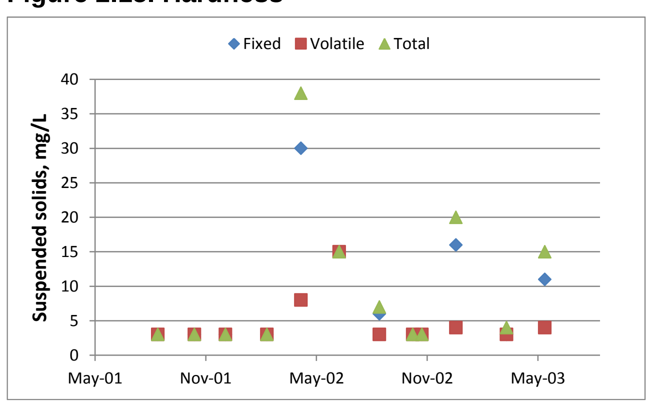

Figure 2.16. Suspended Solids 2001-12003

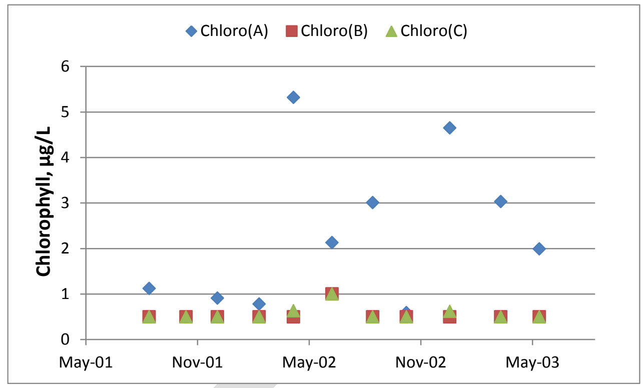

Figure 2.17. Chlorophyll 2001-2003

2.8.2. **FOSR Ambient Monitoring Data**

Ambient bi-weekly monitoring has been performed on the Happy Creek impaired segment at 5 locations by the Friends of the Shenandoah River (FOSR) throughout the watershed since January 2007, with various periods of record. Site 1BHPY-FW09-FOSR (FW09), near the outlet of Happy Creek, has been monitored through May 2009. Site 1BHPY-FW10-FOSR (FW10) above the confluence with Sloan Creek has been monitored through September 2008. Site 1BHPY-FW11-FOSR (FW11), coincident with DEQ station 1BHPY002.67, has been monitored through the present. Site 1BHPY-FW27-FOSR (FW27), also near the outlet, was monitored through July 2008. Site 1BHPY-FW29-FOSR (FW29) on Leach Run, was monitored through May 2009.

Plots of monthly ambient water quality monitoring sample data for all FOSR ambient monitoring stations on Happy Creek are shown in Figure 2.18 through Figure 2.24.

Field physical parameters include water temperature, pH, and DO. Chemical parameters include: ammonia; nitrate-N; orthophosphate-P; and turbidity.

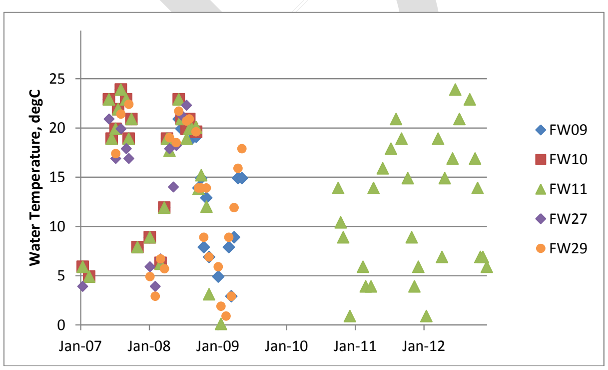

Figure 2.18. FOSR Water Temperature

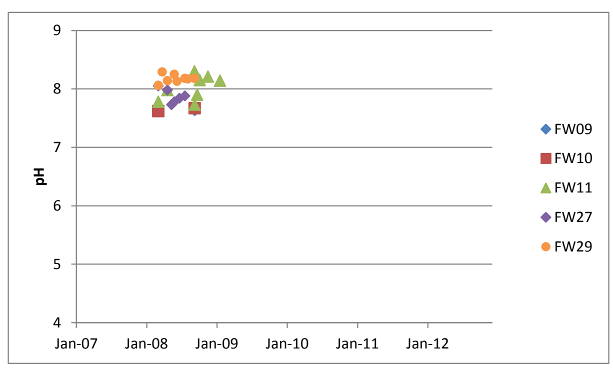

Figure 2.19. FOSR pH

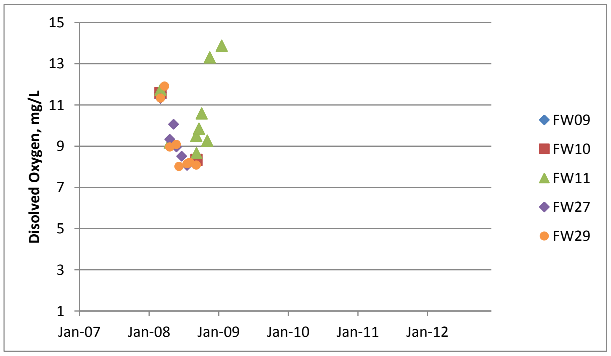

Figure 2.20. FOSR Dissolved Oxygen

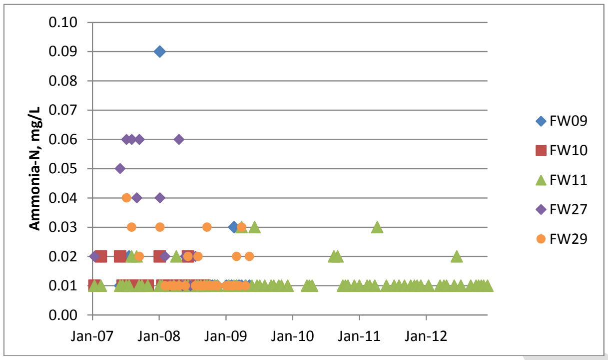

Figure 2.21. FOSR Ammonia

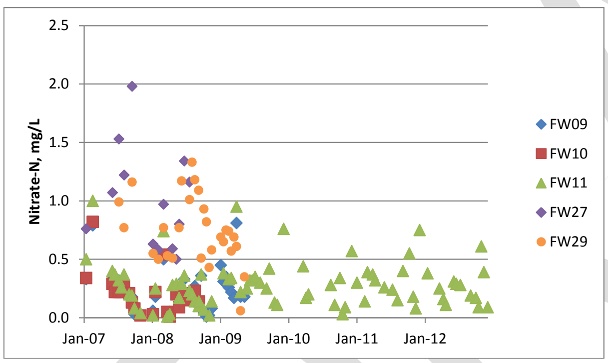

Figure 2.22. FOSR Nitrate-N

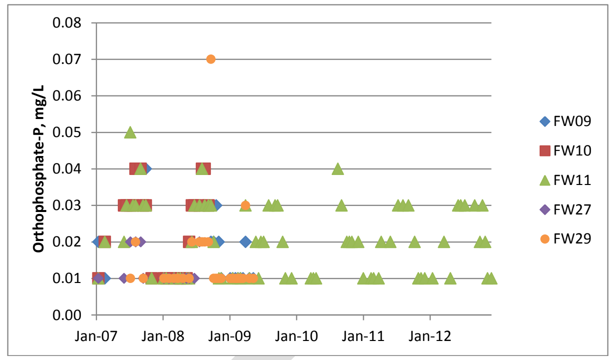

Figure 2.23. FOSR Orthophosphate-P

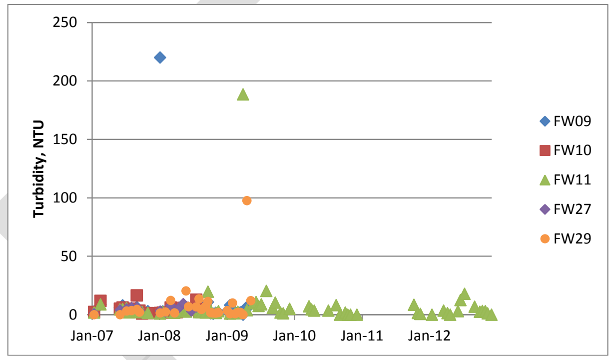

Figure 2.24. FOSR Turbidity

2.8.3. **DEQ Stream Tests for Metals and Organic Compounds**

One sediment sample was collected for Happy Creek watershed at station 1BHPY002.67 on June 2, 2008 and analyzed by DEQ for a standard suite of metals.

None of the tested substances exceeded any established consensus-based probable effects concentration (PEC) screening criteria (MacDonald et al., 2000), only copper barely exceeded its minimum threshold effects concentration (TEC), and most of the metals were not detected above their respective minimum detection limit (MDL) indicated by a Comment Code = “U”, as shown in Table 2.1414.

Table 2.14. DEQ Channel Bottom Sediment Monitoring and Screening Criteria for Metals

Parameter Name	Concentration (mg/kg)	Comment Code	Consensus-Based Criteria	
			TEC (mg/kg)	PEC (mg/kg)
ARSENIC IN BOTTOM DEPOSITS (MG/KG AS AS DRY WGT)	5	U	9.79	33
BERYLLIUM IN BOTTOM DEPOSITS(MG/KG AS BE DRY WGT)	5	U		
CADMIUM,TOTAL IN BOTTOM DEPOSITS (MG/KG,DRY WGT)	1	U	0.99	4.98
CHROMIUM,TOTAL IN BOTTOM DEPOSITS (MG/KG,DRY WGT)	26.6		43.4	111
COPPER IN BOTTOM DEPOSITS (MG/KG AS CU DRY WGT)	38.9		31.6	149
LEAD IN BOTTOM DEPOSITS (MG/KG AS PB DRY WGT)	19.3		35.8	128
MANGANESE IN BOTTOM DEPOSITS (MG/KG AS MN DRY WGT)	820			
NICKEL, TOTAL IN BOTTOM DEPOSITS (MG/KG,DRY WGT)	15.5		22.7	48.6
SILVER IN BOTTOM DEPOSITS (MG/KG AS AG DRY WGT)	1	U	0	0
ZINC IN BOTTOM DEPOSITS (MG/KG AS ZN DRY WGT)	98		121	459
ANTIMONY IN BOTTOM DEPOSITS (MG/KG AS SB DRY WGT)	5	U		
ALUMINUM IN BOTTOM DEPOSITS (MG/KG AS AL DRY WGT)	12100			
SELENIUM IN BOTTOM DEPOSITS (MG/KG AS SE DRY WGT)	1	U		
IRON IN BOTTOM DEPOSITS (MG/KG AS FE DRY WGT)	47900			
THALLIUM DRY WGTBOTMG/KG	5	U		
MERCURY,TOT. IN BOT. DEPOS. (MG/KG AS HG DRY WGT)	0.1	U	0.18	1.06

U = parameter analyzed, but not detected.
TEC = Threshold effects concentration; PEC = Probable effects concentration.

One sample analyzed for dissolved metals was taken on the same day as the sediment metals sample. These results are shown in Table 2.15. No samples exceeded any of the applicable freshwater aquatic life or human health criteria.

Table 2.15. Dissolved Metals Monitoring and Screening Criteria

Parameter Name	Value	Comment Code	Aquatic Life Freshwater Criteria		Human Health Criteria	
			Acute (µg/L)	Chronic (µg/L)	Public Well Supplies	Other Surface Waters (µg/L)
CALCIUM, DISSOLVED (MG/L AS CA)	16.59					
CALCIUM, TOTAL (MG/L AS CA)	16.6					
MAGNESIUM, DISSOLVED (MG/L AS MG)	4.73					
MAGNESIUM, TOTAL (MG/L AS MG)	4.7					
ARSENIC, DISSOLVED (UG/L AS AS)	0.12		360	190		
ARSENIC, TOTAL (UG/L AS AS)	0.1	U				
BARIUM, DISSOLVED (UG/L AS BA)	13.65					
BARIUM, TOTAL (UG/L AS BA)	13.8					
BERYLLIUM, DISSOLVED (UG/L AS BE)	0.1	U				
CADMIUM, DISSOLVED (UG/L AS CD)	0.1	U	3.9	1.1		
CADMIUM, TOTAL (UG/L AS CD)	0.1	U				
CHROMIUM, DISSOLVED (UG/L AS CR)	0.38		1,700	210		
CHROMIUM, TOTAL (UG/L AS CR)	1.41					
COPPER, DISSOLVED (UG/L AS CU)	0.13		18	12	1,300	
COPPER, DISSOLVED (UG/L AS CU)	0.69					
COPPER, TOTAL (UG/L AS CU)	0.7					
IRON, TOTAL (UG/L AS FE)	165					
IRON, DISSOLVED (UG/L AS FE)	50	U				
LEAD, DISSOLVED (UG/L AS PB)	0.1	U	120	14	15	
LEAD, TOTAL (UG/L AS PB)	0.1	U				
MANGANESE, TOTAL (UG/L AS MN)	11.7					
MANGANESE, DISSOLVED (UG/L AS MN)	3.17					
THALLIUM, DISSOLVED (UG/L AS TL)	0.1	U				
THALLIUM, TOTAL (UG/L AS TL)	0.1	U				
NICKEL, DISSOLVED (UG/L AS NI)	0.12		180	20	610	4,600
NICKEL, TOTAL (UG/L AS NI)	0.19					
SILVER, DISSOLVED (UG/L AS AG)	0.1	U	4.1			
SILVER, TOTAL (UG/L AS AG)	0.1	U				
ZINC, DISSOLVED (UG/L AS ZN)	1	U	120	110	5,000	
ZINC, TOTAL (UG/L AS ZN)	1	U				
ANTIMONY, DISSOLVED (UG/L AS SB)	0.5	U				
ANTIMONY, TOTAL (UG/L AS SB)	0.5	U				
ALUMINUM, TOTAL (UG/L AS AL)	47.2					
ALUMINUM, DISSOLVED (UG/L AS AL)	2.97					
SELENIUM, DISSOLVED (UG/L AS SE)	0.5	U	20	5	170	11,000
SELENIUM, TOTAL (UG/L AS SE)	0.5	U				
MERCURY-TL,FILTERED WATER,ULTRATRACE METHOD UG/L	0.0015	U	2.4	0.012	0.052	0.053
MERCURY-TL,UNFILTERED WATER,ULTRATRACE METHOD UG/L	0.00173					
		U = parameter analyzed, but not detected.				

2.8.4. **DEQ – Other Relevant Monitoring or Reports**

Relative Bed Stability (RBS) Analysis

EPA's Log Relative Bed Stability (LRBS) index is a type of siltation index. The LRBS is the ratio of the observed mean streambed particle diameter to the expected mean streambed particle diameter (Kaufmann et al., 1999, Kaufmann et al., 2008). The expected mean streambed particle diameter is calculated from field measurements of the size, slope, and other physical characteristics of the stream channel and the observed mean streambed particle diameter is the result of instream particle measurements. An

LRBS score of negative one (-1) indicates that sediments ten times larger than the median are moving at bankfull, with a medium probability of impairment from sediment. LRBS scores < -1 are considered sub-optimal, while scores > -0.5 are considered optimal. The stream has a relatively high percentage of mean embeddedness according to this test. The LRBS scores upstream are in an optimal range, while the downstream site shows a greater impact from sediment, though not in the sub-optimal range. The regional DEQ biologist stated that the assessment of the benthic impairment as being due to habitat problems is unclear.

Happy Creek has a relatively steep slope along its length resulting in efficient transport of sediment from upstream erosion, as shown in Table 2.16, although it has relatively high percentages of bedrock, sand, and fines, the least usable substrates for good benthic macro-invertebrate habitat. A high percentage of fine sediment in streams would directly contribute to embeddedness, the filling of the interstitial spaces in the channel bottom.

Table 2.16. RBS Analysis Results

Station ID	Date	% Slope	% Bedrock	% Sand + Fines	Embeddedness	LRBS
1BHPY001.29	07/26/12	0.900	0%	31%	41.7	-0.816
1BHPY002.67	09/22/08	1.154	23%	33%	37.6	-0.218
1BHPY002.67	07/31/12	1.640	20%	32%	33.6	-0.225

2.8.5. **Permitted Point Sources**

There are no general discharge permits for single-family homes or VPDES permits in the Happy Creek watershed.

There is currently one Industrial Stormwater General Permit in the watershed, as shown in Table 2.177.

Table 2.17. Industrial Stormwater General Permitted Discharges

Permit No	Facility Name	Water Body	Receiving Stream
VAR050852	Zuckerman Metals, Inc.	VAV-B41R	Happy Creek

2.8.6. **DEQ Pollution Response Preparedness Reports**

The following spills or other illegal discharges were reported to DEQ's Pollution Response Preparedness (PReP) program between 2001 and 2012. None of these discharges appeared to directly influence any of the water quality monitoring data assessed during the stressor analysis.

01/20/01: Gasoline spill enters storm sewer; 500 gal

11/16/06: Sewage overflow due to heavy rain; unknown volume (UNK)

08/15/08: Improper pond cleanout, sediment; UNK

09/22/08: Manhole overflowing; UNK

07/19/09: Sewage overflow; 15,000 gal

01/25/10: Sewage overflow at STP; 60,000 gal

2.8.7. **305(b)/303(d) Integrated Report – Monitored Exceedences**

In the three biennial reports for 2008, 2010, and 2012 (VADEQ, 2008, 2010, and 2012), stations 1BHPY001.29 and 1BHPY002.67 on Happy Creek were consistently listed with a biological impairment.

2.8.8. **VAHWQP Household Drinking Water Analyses**

The Virginia Cooperative Extension Virginia Household Water Quality Program (VAHWQP) conducted Drinking Water Clinics in Warren County in June 2012, where homeowners brought in samples from private water supply systems (wells or springs). Samples were generally collected from a faucet or tap inside the house. Table 2.18 provides a summary of the Drinking Water Clinic data. While the samples may not be directly representative of the groundwater quality in the area, they do provide some information on general levels of physical and chemical parameters that may be impacted by groundwater. The VAHWQP uses the EPA primary and secondary standards of the Safe Drinking Water Act, which are enforced for public systems as guidelines for private water supplies.

Table 2.18. VAHWQP County Drinking Water Clinic Results, Benham et al., 2013

2012 Warren County
VAHWQP Drinking Water Clinic Results
N = 44 samples

Test	EPA Standard	Average	Maximum Value	% Exceeding Standard
Iron (mg/L)	0.3	0.237	2.804	18.2
Manganese (mg/L)	0.05	0.073	1.102	18.2
Hardness (mg/L)	180	90.7	373.5	22.7
Sulfate (mg/L)	250	101	1344	6.8
Fluoride (mg/L)	2.0/4.0	0.16	1.35	0.0
Total Dissolved Solids	500	273	941	11.4
pH	6.5 to 8.5	7.0	6.1 (min) 7.9 (max)	13.6 (<6.5) 0 (>8.5)
Sodium (mg/L)	20	43.26	248.2	31.8
Nitrate - N (mg/L)	10	1.799	17.338	2.3
Copper-First Draw (mg/L)	1.0/1.3	0.591	5.367	15.9
Copper-Flushed (mg/L)	1.0/1.3	0.065	1.417	2.3
Lead-First Draw (mg/L)	0.015	0.006	0.029	13.6
Lead-Flushed (mg/L)	0.015	0	0.002	0.0
Arsenic-First Draw (mg/L)	0.010	DL	0	0.0
Arsenic-Flushed (mg/L)	0.010	DL	0	0.0
Total Coliform Bacteria	ABSENT	91	1708	47.7
E. coli Bacteria	ABSENT	0	12	4.5

Chapter 3: Benthic Stressor Analysis

3.1. *Introduction*

TMDLs must be developed for a specific pollutant. Since a benthic impairment is based on a biological inventory, rather than on a physical or chemical water quality parameter, the pollutant is not explicitly identified in the assessment, as it is with physical and chemical parameters. The process outlined in USEPA's Stressor Identification Guidance Document (USEPA, 2000) was used to identify the critical stressor for the each of the impaired stream segments in this study. A list of candidate causes was developed from the listing information, biological data, published literature, and stakeholder input. Chemical and physical monitoring data from DEQ provided additional evidence to support or eliminate the potential candidate causes. Biological metrics and habitat evaluations in aggregate provided the basis for the initial impairment listing, but individual metrics were also used to look for links with specific stressors, where possible. Volunteer monitoring data, land use distribution, Google Earth aerial imagery, and visual assessment of conditions in and along the stream corridor provided additional information to investigate specific potential stressors. Logical pathways were explored between observed effects in the benthic community, potential stressors, and intermediate steps or interactions that would be consistent in establishing a cause and effect relationship with each candidate cause. The candidate benthic stressors included ammonia, hydrologic modifications, nutrients, organic matter, pH, sediment, TDS/conductivity/sulfates, temperature, and toxics. The details of the stressor analyses are included in the Happy Creek Stressor Analysis Report (Yagow et al., 2014), dated March 11, 2014, and summarized in the following section.

3.2. *Stressor Analyses Summary*

The Happy Creek stream segments (VAC-B41R_HPY01A00 and VAC-B41R_HPY02A00) are impaired for their aquatic life use. Sediment was selected as the most probable stressor to Happy Creek based on poor riparian vegetation habitat metrics at both sites, along with poor bank stability metrics at the upstream site, poor channel alteration metric scores, and moderate impacts on the LRBS siltation metric shown at the downstream site. See Tables 2.11 and 2.12 for a summary of habitat metrics data, and Section 2.8.4 for a discussion of LRBS data.

Chapter 4: Source Assessment of Fecal Coliform

While the bacteria monitoring data were developed to produce *E. coli* concentrations, the watershed model was developed to simulate the transport and fate of fecal coliform due to the greater availability of fecal coliform production data for various sources. Fecal coliform sources and production rates in the Shenandoah River tributaries watersheds were assessed using information from the following sources: VADEQ, Virginia Department of Conservation and Recreation (VADCR), Virginia Department of Game and Inland Fisheries (VADGIF), Virginia Cooperative Extension (VCE), Natural Resources Conservation Service (NRCS), public participation, watershed reconnaissance and monitoring, published information, and professional judgment. Potential nonpoint sources of fecal coliform in the Shenandoah River tributaries watersheds are summarized in Table 4.1. Additional information regarding the estimation of loads for the various bacteria sources is included in Appendix B.

Table 4.1. Potential fecal coliform sources and daily fecal coliform production by source for existing conditions in the Shenandoah River tributaries watersheds.

Potential Source	Total Estimated Population	Fecal coliform produced (x 10^6 cfu/head/day)
	Shenandoah River Watershed	
Humans (permanent)	25,250	350[a]
Beef Cattle	3,694	8,556[a]
Dairy Cattle	1,322	25,000[b]
Swine	2000	10,800
Goats	392	12,000[d]
Sheep	253	12,000[d]
Poultry	661	140
Horses	935	420[d]
Pets	10,973	450[c]
Deer	4,895	350
Raccoons	1,923	50
Muskrats	147	25[e]
Beavers	18	0.2
Ducks (Offseason)	133	2400
Ducks (Peak)	133	2400
Geese (Offseason)	640	800
Geese (Peak)	640	800
Wild Turkeys	316	93

[a] Source: Geldreich (1978)
[b] Cow-calf pairs
[c] Source: Weiskel *et al*. (1996)
[d] Source: ASAE(1998)
[e] Source: Yagow (2001)

Permitted point sources of fecal coliform bacteria in the Shenandoah River tributaries watersheds are shown in Table 4.2. Virginia issues Virginia Pollutant Discharge Elimination System (VPDES) permits for point sources of pollution. In Virginia, point sources that treat human waste are required to maintain an *E. coli* concentration of 126 cfu/100 mL or less in their effluent. In allocation scenarios for bacteria, load for the permitted point source was calculated as the allowable point source discharge concentration of 126 cfu/100 mL at the facility's permitted maximum design flow rate. General permits for single family homes are summarized in Table 4.2 by subwatershed, and are listed individually in Appendix C. Each general permit has a design flow of 1,000 gallons per day (0.001 mgd).

Table 4.2. Permitted facilities discharging into impaired streams of the Shenandoah River study area.

Permit Number	Facility Name	Sub water -shed	Design Flow (mgd[*])	Permitted *E. coli* Conc. (cfu/100 mL)	***Permitted E. coli*** **Load (cfu/year)**
VA0061964	Forest Lakes Estates STP	11	0.150	126	2.61×10^{11}
VA0092703[b]	RSW Regional Jail WWTP	6	0.020	126	3.48×10^{10}
VA0059170	The Apple House WWTP	30	0.007	126	1.22×10^{10}
VA0090247	Jacksons Chase WWTP	2	0.020	126	3.48×10^{10}
VA0088811	Sandys MHC LLC STP	13	0.040	126	6.97×10^{10}
VA0023370	DOC - White Post Correctional Unit 7	10	0.037	126	6.45×10^{10}
VA0080080	Crooked Run STP	12	0.250	126	4.35×10^{11}
VA0086100[b]	Bierer STP	6	0.350	126	6.09×10^{11}
VA0089958	Apple Mountain Exxon	30	0.0055	126	9.58×10^{9}
VA0089095[b]	Pioneer Trailer Park	11	0.005	126	8.70×10^{9}
3 Gen. Permits	Single Family Homes	1	0.003	126	5.23×10^{9}
10 Gen. Permits	Single Family Homes	2	0.010	126	1.74×10^{10}
14 Gen. Permits	Single Family Homes	3	0.014	126	2.44×10^{10}
15 Gen. Permits	Single Family Homes	4	0.015	126	2.61×10^{10}

Permit Number	Facility Name	Sub water -shed	Design Flow (mgd*)	Permitted *E. coli* Conc. (cfu/100 mL)	*Permitted E. coli* Load (cfu/year)
10 Gen. Permits	Single Family Homes	5	0.010	126	1.74×10^{10}
4 Gen. Permits	Single Family Homes	6	0.004	126	6.97×10^{9}
13 Gen. Permits	Single Family Homes	8	0.013	126	2.26×10^{10}
1 Gen. Permits	Single Family Homes	10	0.001	126	1.74×10^{9}
15 Gen. Permits	Single Family Homes	11	0.015	126	2.61×10^{10}
7 Gen. Permits	Single Family Homes	13	0.007	126	1.22×10^{10}
1 Gen. Permits	Single Family Homes	15	0.001	126	1.74×10^{9}
1 Gen. Permits	Single Family Homes	19	0.001	126	1.74×10^{9}
3 Gen. Permits	Single Family Homes	30	0.003	126	5.23×10^{9}
4 Gen. Permits	Single Family Homes	31	0.004	126	6.97×10^{9}

[a]million gallons per day
[b]Historical permit – permit not active and received no WLA

4.1. *Summary: Contributions from All Sources*

Based on the inventory of sources discussed in this chapter and Appendix B, in addition to the land-based sources, an estimate of the contributions by the different nonpoint sources directly to the annual fecal coliform loading in streams is summarized in Table 4.3. The estimated distribution of annual fecal coliform loading from land-based nonpoint sources among the different land use categories is also included in Table 4.3. From Table 4.3, it is clear that nonpoint source loadings to the land surface are greater than direct nonpoint source loadings to the stream. Pastures receive the greatest portion of this load, at 91.7% in the Shenandoah River tributaries watersheds. However, factors such as precipitation amount and pattern, die-off rates, manure application activities, type of waste, and proximity to the streams impact the amount of fecal coliform from upland areas that reaches the streams. Due to their nature, direct nonpoint source loadings enter the stream without attenuation. The HSPF model discussed in Chapter 6 considers these factors when estimating fecal coliform loadings in the receiving waters.

Table 4.3. Estimated annual fecal coliform loadings to the stream and the various land use categories for the Shenandoah River tributaries watersheds.

Source	Fecal coliform loading (x10^{12} cfu/yr)	Percent of total loading
Direct loading to streams		
Livestock in stream	42	0.13%
Wildlife in stream	23	<0.1%
Straight pipes	1	<0.1%
Loading to land surfaces		
Hayland	68	0.21%
Cropland	40	0.12%
Pasture	29,136	91.7%
Developed	2,021	6.36%
Forest	431	1.36%
Total	**31,762**	

Chapter 5: Setting Reference TMDL Loads for Sediment

Since there are no in-stream water quality standards for sediment in Virginia, an alternate method was needed for establishing a reference endpoint that would represent the “non-impaired” condition.

5.1. *Sediment*

In the past, a reference watershed approach has been used based on a single reference watershed that has similar characteristics as the TMDL watershed, except that it has a healthy benthic community. In the reference watershed approach, the modeled sediment load in the reference watershed is set as the TMDL (threshold) level in the impaired watershed. One problem with this reference watershed approach can be finding a suitable reference watershed, especially for minimally-impaired and urban watersheds. A second problem is in identifying the threshold sediment load that is sufficient, without being excessive for attainment of biological integrity in the impaired watershed, since the load from the reference watershed may be overly conservative.

For the Happy Creek sediment impairments, the procedure used to set TMDL sediment endpoint loads is a modification of the methodology used to address sediment impairments in Maryland’s non-tidal watersheds (MDE, 2006, 2009), hereafter referred to as the “all-forest load multiplier” (AllForX) approach. AllForX is the ratio of the simulated sediment load for existing conditions to the sediment load from an all-forest condition for the same watershed. The AllForX approach was applied locally for Happy Creek, using a selection of watersheds with monitoring stations that have healthy biological scores. A regression was developed between the average Virginia Stream Condition Index (VSCI) biological index scores at impaired and selected comparison monitoring stations and the corresponding AllForX ratio from their contributing watersheds. The full AllForX methodology is detailed in Appendix G.

5.1.1. **Selection of Local Comparison Watersheds**

The AllForX comparison watersheds were selected using these criteria:

- nearby watersheds (within 30 miles)

- Average VSCI > 60 and a minimum VSCI > 55
- Minimum of 3 VSCI samples
- The most recent VSCI sample has been since January 2005
- 2nd – 4th order streams
- No upstream-downstream comparison watersheds

Nine potential comparison watersheds were identified for application of the AllForX approach with the two sampling locations in the Happy Creek watershed. After performing load calculations, the number of comparison watersheds was reduced to three, as AllForX values for six of the watersheds were larger than those of the two Happy Creek stations, and therefore, not appropriate for setting sediment reduction targets for Happy Creek. Since one or more additional comparison watersheds were desired for the AllForX regression, modeling was performed on additional potential comparison watersheds and Manassas Run was added to the list as a fourth comparison watershed, even though its minimum VSCI was slightly outside the criteria listed above. Table 5.1 summarizes the various characteristics in support of the selection criteria, while Figure 5.1 illustrates the location of the comparison watersheds to the Happy Creek watersheds corresponding to each of the DEQ biomonitoring stations. The highlighted watersheds in Table 5.1 are the final selected comparison watersheds.

Table 5.1. Summary of Comparison Watershed Characteristics

StationID	Stream Name	Sub-ecoregion Code	Ecoregion	VAHU6	No. of Samples	Min VSCI	Ave VSCI	First Sampling Date	Last Sampling Date
1ABEC004.76	Beaverdam Creek	64c	Northern Piedmont	PL11	4	55.1	71.3	04/05/10	11/04/11
1AHOC006.23	Hogue Creek	67b	Central Appalachian Ridges and Valleys	PU12	11	57.1	65.4	10/07/97	04/01/10
1ANOC009.37	N. Fk. Catoctin Creek	66a	Blue Ridge	PL02	3	55.6	63.3	05/06/10	10/05/11
1BHKS000.96	Hawksbill Creek	67a	Central Appalachian Ridges and Valleys	PS43	15	61.9	71.5	05/20/92	10/06/11
1BMIL005.67	Mill Creek	67a	Ridge and Valley	PS63	5	60.7	66.9	05/06/05	04/16/13
3-FIR002.35	Fiery Run	64c	Northern Piedmont	RA01	3	59.8	60.7	07/03/01	09/15/08
3-HUE000.20	Hughes River	64c	Northern Piedmont	RA08	32	60.7	68.1	09/23/94	11/19/12
3-ROE000.75	Rose River	64c	Northern Piedmont	RA31	11	57.4	66.5	05/24/06	10/26/10
3-THU006.90	Thumb Run	64c	Northern Piedmont	RA04	4	55.7	65.9	03/15/04	09/28/05
1BMAN002.55	Manassas Run	66b	Blue Ridge	PS80	6	54.6	66.5	04/09/08	03/28/12

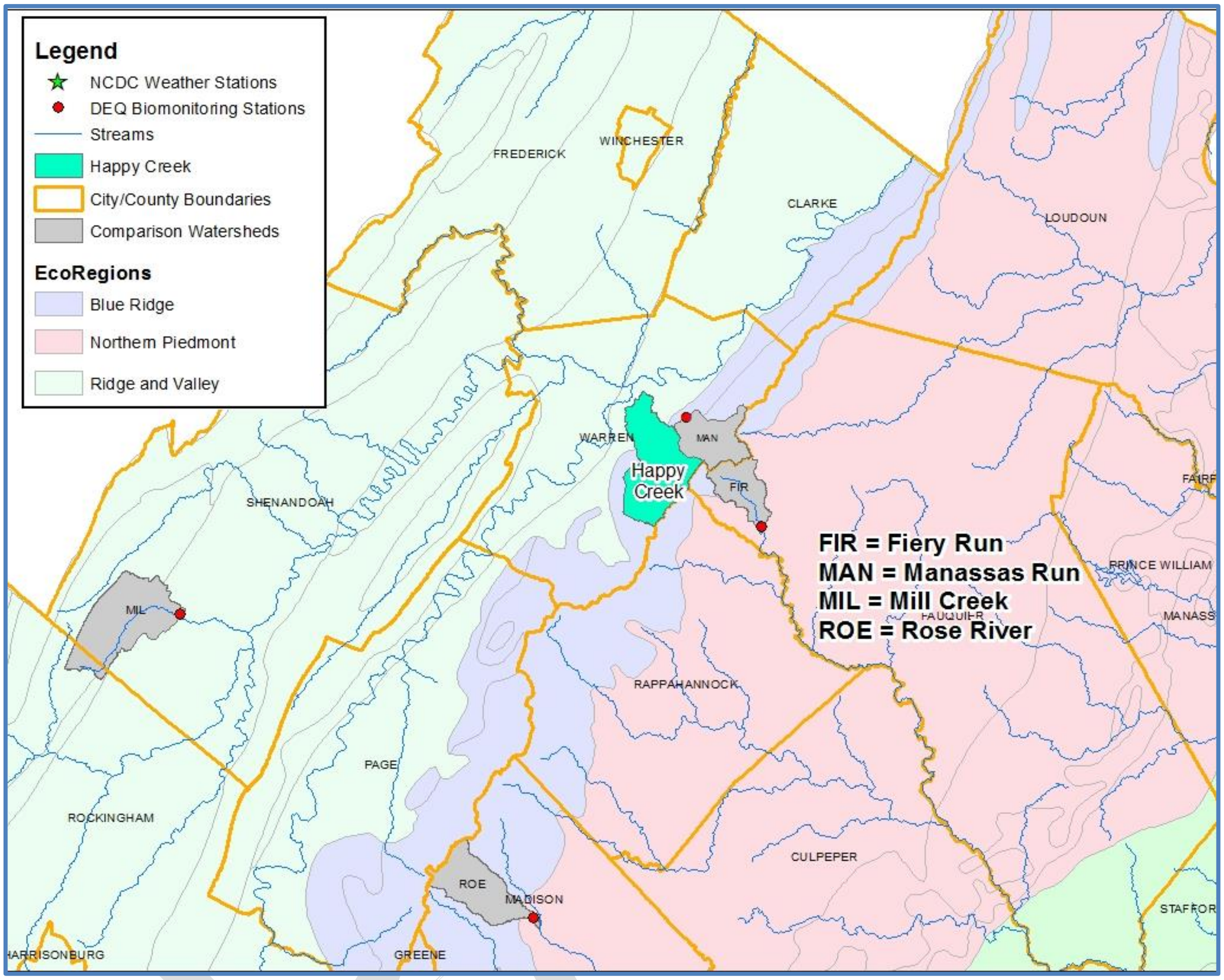

Figure 5.1. Location of Happy Creek and Comparison Watersheds

Although these TMDLs are developed for sediment, attainment of a healthy benthic community will ultimately be based on biological monitoring of the benthic macro-invertebrate community, in accordance with established DEQ protocols. If a future review should find that the reductions called for in these TMDLs based on current modeling are found to be insufficiently protective of local water quality, then revision(s) will be made as necessary to provide reasonable assurance that water quality goals will be achieved.

Chapter 6: Modeling Process for Bacteria TMDL Development

A key component in developing a TMDL is establishing the relationship between pollutant loadings (both point and nonpoint) and in-stream water quality conditions. Once this relationship is developed, management options for reducing pollutant loadings to streams can be assessed. In developing a TMDL, it is critical to understand the processes that affect the fate and transport of the pollutants and cause the impairment of the water body of concern. Pollutant transport to water bodies is evaluated using a variety of tools, including monitoring, geographic information systems (GIS), and computer simulation models. In this chapter, the modeling process, input data requirements, and model calibration procedure and results are discussed. Additional detail describing the development and evaluation of the hydrology and water quality models is contained in Appendix C.

6.1. ***Model Description***

The TMDL development process requires the use of a watershed-based model that integrates both point and nonpoint sources and simulates in-stream water quality processes. The Hydrologic Simulation Program – FORTRAN (HSPF) version 12 (Bicknell et al., 2005; Duda et al., 2001) was used to model fecal coliform transport and fate in the bacteria TMDL study watersheds. The ArcGIS 10 GIS software was used to display and analyze landscape information for the development of input to HSPF.

The HSPF model simulates nonpoint source runoff and pollutant loadings, performs flow routing through streams, and simulates in-stream water quality processes. HSPF estimates runoff from both pervious and impervious parts of the watershed and stream flow in the channel network. The sub-module PWATER within the module PERLND simulates runoff, and hence, estimates the water budget, on pervious areas (e.g., agricultural and pervious urban land). Runoff from impervious areas is modeled using the IWATER sub-module within the IMPLND module. The simulation of flow through the stream network is performed using the sub-modules HYDR and ADCALC within the module RCHRES. While HYDR routes the water through the stream network, ADCALC calculates variables used for simulating convective transport of the pollutant in the stream.

Fate of fecal coliform on pervious and impervious land segments is simulated using the PQUAL (PERLND module) and IQUAL (IMPLND module) sub-modules, respectively. Fate of fecal coliform in stream water is simulated using the general constituent pollutant (GQUAL) sub-module within the RCHRES module. Fecal coliform bacteria are simulated as dissolved pollutants in the GQUAL sub-module.

One set of model inputs? was developed to simulate all eight bacteria TMDL study watersheds. The watershed model included watershed outlets at the mouth of each study watershed.

6.2. *Model Evaluation, Calibration, and Validation*

Evaluation is the process of assessing the performance of a watershed model. Model calibration is the process of selecting model parameters that provide an accurate representation of the watershed, and reproduce observed in-stream flow and concentrations. In this section, the procedures followed for calibrating the hydrology and water quality components of the Hydrological Simulation Program-FORTRAN (HSPF) model are discussed.

6.2.1. **Hydrology**

Surrogate watersheds were used to develop a hydrology model for all eight study watersheds. Stream flow gaging stations were once located in the Manassas Run and Crooked Run watersheds near the mouth of the respective streams. However, data from these gages were determined to be not suitable for hydrology model calibration and validation as both gages produced data for a limited time (5-7 years), both gages were discontinued in 2009, and all data produced by the gages are provisional. However, the limited data available from these gages were used to provide an assessment of the performance of the hydrology models developed using the surrogate watershed models.

A thorough surrogate analysis was performed, and Technical Advisory Committee input was incorporated, to identify suitable surrogates for the study watersheds. Ultimately, the Spout Run watershed was identified as the most suitable surrogate for all eight study watersheds. This process is described in greater detail in Appendix C.

Prior to assessing the Manassas Run and Crooked Run results from the hydrology model, the approach to the assessment and evaluation was established. Because this operation falls somewhere between surrogate watershed use and model calibration, and since surrogate-derived hydrology models are not normally evaluated due to a complete lack of observed stream flow data, normal model evaluation criteria were not applied. Due to the presence of karst topography, the apparent losing nature of the streams, and the simulation of minimum spring flows in the study watershed models, only spring flow estimates and the parameter DEEPFR were adjusted in the course of the assessment. No further adjustments were made during evaluation using the Nash-Sutcliffe Efficiency (NSE) statistic.

The performances of the Manassas Run and Crooked Run portions of the hydrology model were assessed using the performance statistics normally used by the Biological Systems Engineering (BSE) Department to evaluate the performance of calibrated and validated watershed models. However, the associated calibration criteria normally used during model calibration were not applied in this instance, given that the models were not being calibrated, but are listed for reference. Flow partitioning in the form of baseflow was evaluated using a composite target range developed for the surrogate watersheds. All baseflow analyses were performed using the Baseflow Program (Arnold, 1999). Finally, the NSE statistic was used to determine if the performance of the hydrology model for the Manassas Run and Crooked Run portions of the hydrology model was generally acceptable.

6.2.1.1. Hydrologic Model Evaluation for the Manassas Run Watershed

Manassas Run was assessed for the period 1/1/2003 – 12/31/2008. Multiple precipitation gage records were evaluated, as described in Appendix C, and data from the Front Royal precipitation gage was found to be most suitable and was used for this model portion evaluation and subsequent project phases. One adjustment was made from the initial model. The estimated low flow values from springs in the Manassas Run watershed were reduced by 50%. The initial DEEPFR value of 0.45 from the surrogate watershed model (Spout Run) was not changed. The resulting summary statistics are presented in Table 6.1. A visual comparison of observed stream flow, simulated stream flow, and precipitation are included in Figure 6.1.

Table 6.1. Summary statistics for the calibration for Manassas Run at sub-watershed #29

	Simulated	Observed	Error (%)	Calibration Criterion[1]
Total Runoff (in)	74.64	92.34	-19.2	10%
Average Annual Total Runoff (in)	12.44	15.39	-19.2	10%
Total of Highest 10% of flows (in)	28.65	39.23	-26.9	15%
Total of Lowest 50% of flows (in)	13.45	11.30	19.0	10%
Total Winter Runoff (in)	17.88	23.11	-22.6	na
Total Summer Runoff (in)	14.51	14.12	2.8	na
Coefficient of Determination, r^2	0.41			

1 – Calibration criteria do not apply in assessing surrogate-derived hydrology model performance. These values are included for reference only.
na = not applicable; these are not criteria directly considered by HSC

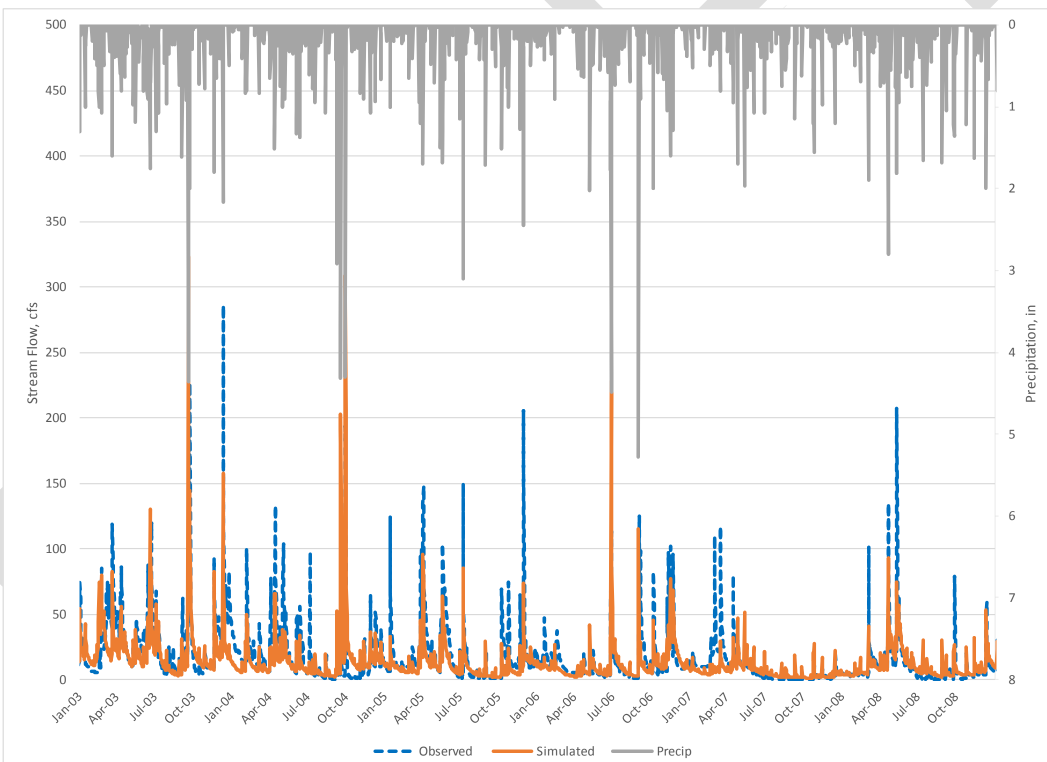

Figure 6.1. Comparison of observed and simulated flow at sub-watershed #29 in Manassas Run watershed.

The NSE statistic is a normalized metric that determines the relative magnitude of the residual variance, or noise, compared to the measured data variance (Moriasi et al., 2007). When comparing simulated and observed data, values of NSE between 0 and 1 are considered indicative of an acceptable level of model performance, with a value of 1 indicating a perfect fit along the 1:1 line. Values of NSE $\leq$ 0.0 indicate poor model performance. An NSE value of 0.5 or greater is considered satisfactory for model calibration using measured data of typical uncertainty, which is not the case in this instance. Since the model is being evaluated using very limited observed data, and not calibrated using more extensive observed data, an NSE value greater than 0.0 is considered acceptable. For the period evaluated, the Manassas Run hydrology model exhibited an NSE value of 0.36, and is therefore considered to have an acceptable level of model performance. The value of NSE did not change significantly from the pre-adjustment value of 0.37.

Baseflow is generally the portion of stream flow that comes from subsurface sources. The resulting baseflow from the Manassas Run hydrology model was compared to a target and potential range of baseflow values exhibited by the three potential surrogate watersheds, as identified in Table 6.2. The three potential surrogates were identified and considered during the surrogate analysis, described in Appendix C. All three potential surrogates were used in this instance to provide a range of realistic baseflow values.

The median baseflow exhibited by the Manassas Run hydrology model, determined using the Baseflow Program, was 0.57. This value is within the target range identified in Table 6.2.

Table 6.2. Baseflow values for each surrogate and resulting Target and Potential ranges.

Station ID	Stream	Maximum	Minimum
USGS01613900	Hogue Run	0.53	0.31
USGS01615000	Opequon Creek	0.55	0.36
USGS01636316	Spout Run	0.85	0.72
	Target Range (Mean)	**0.64**	**0.46**
	Potential Range (Min/Max)	**0.85**	**0.31**

6.2.1.2. Hydrologic Model Evaluation for the Crooked Run Watershed

The Crooked Run model was assessed for the period 11/1/2004 – 10/19/2009. Multiple precipitation gage records were evaluated, as described in Appendix C, and data from the Winchester precipitation gage was found to be most suitable and was used for this model evaluation and subsequent project phases. Adjustments were made from the initial surrogate-derived model. All spring flows in the Crooked Run watershed were turned off, and the parameter DEEPFR was adjusted to 0.9 from the 0.45 included in the Spout Run surrogate model. The DEEPFR value of 0.9 exceeds the maximum value of 0.5 identified in BASINS Technical Note 6 (EPA, 2000). However, Crooked Run appears to lose significant flow to subsurface geology, and is located in Karst topography, and so appears to be reasonable under the circumstances. The Crooked Run watershed has an area of 30,250 acres and an observed mean average annual total runoff of 9.61 inches. By contrast, the Manassas Run watershed has an area of 9,400 acres with an observed mean average annual total runoff of 15.39 inches. The resulting summary statistics are presented in Table 6.3. It should be noted that the highest errors are associated with low and summer (also low) flows. For these low flows, with low absolute values, a small absolute error value can result in a high % error. A visual comparison of observed stream flow, simulated stream flow, and precipitation are included in Figure 6.2.

Table 6.3. Summary statistics for the calibration for Crooked Run at sub-watershed #1

	Simulated	Observed	Error (%)	Calibration Criterion[1]
Total Runoff (in)	41.98	38.44	9.2	10%
Average Annual Total Runoff (in)	10.49	9.61	9.2	10%
Total of Highest 10% of flows (in)	14.02	21.15	-33.7	15%
Total of Lowest 50% of flows (in)	8.40	4.36	92.6	10%
Total Winter Runoff (in)	10.70	10.93	-2.0	na
Total Summer Runoff (in)	9.21	5.30	73.9	na
Coefficient of Determination, r^2	0.11			

1 – Calibration criteria do not apply in assessing surrogate-derived hydrology model performance. These values are included for reference only.
na = not applicable; these are not criteria directly considered by the Hydrology Statistics Calculator (HSC)

For the period evaluated, the Crooked Run hydrology model exhibited an NSE value of 0.41, and is therefore considered to have a generally acceptable level of model performance. This value represents an increase from the NSE value of 0.21 exhibited prior to model adjustment.

The median baseflow exhibited by the Crooked Run hydrology model, determined using the same Baseflow Program, was 0.48. This is within the target range identified in Table 6.2.

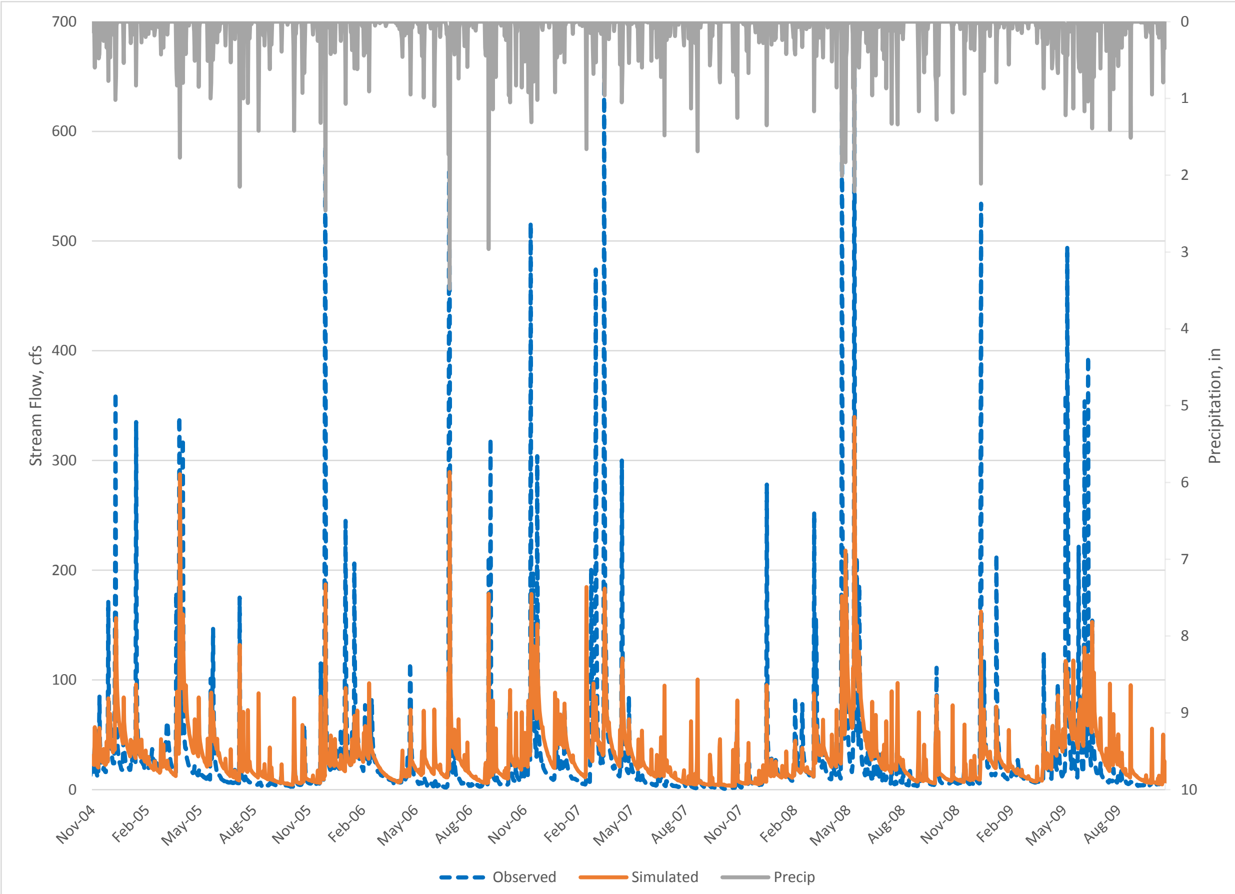

Figure 6.2. Comparison of observed and simulated flow at sub-watershed #1 in Crooked Run watershed.

6.2.2. **Water Quality**

The water quality model calibration and validation for the Shenandoah River tributaries watersheds were performed at an hourly time step using the HSPF model. Limited observations of bacterial water quality were available for some stations in the watershed, while other stations had more suitable quantities of data available for use. All data used for calibration and validation were observed *E. coli* concentration data. VADEQ's *E. coli* translator regression equation was used to translate the fecal coliform model results to *E. coli* concentrations for comparison to observed *E. coli* concentration data.

Data from the following VADEQ monitoring stations were used for the calibration and/or validation for the Shenandoah River study area: 1BBMR000.20 (Borden Marsh

Run), 1BCRO002.75 (Crooked Run), 1BLNG000.24 (Long Branch), 1BSTV000.20 (Stephens Run), 1BWST000.20 (West Run), and 1BWLO000.71 (Willow Brook) had sufficient data for both calibration and validation. Stations 1BHPY001.29 (Happy Creek), 1BHPY002.67 (Happy Creek), and 1BMAN002.55 (Manassas Run) only had sufficient data to allow for calibration.

Output from the HSPF model was generated as an hourly time series and daily average time series of *E. coli* concentration at the sub-watershed outlets that correspond to the locations of the water quality model calibration stations. The VADEQ *E. coli* translator (Equation. 6.1) was implemented using the GENER block in HSPF to calculate instream *E. coli* concentration data compared to observed data during calibration, validation, and later during existing conditions modeling and allocation. The geometric mean of *E. coli* concentrations was calculated on a monthly basis.

$$\log_2 EC(cfu/100mL) = -0.0172 + 0.91905 * \log_2 FC(cfu/100mL) \qquad [6.1]$$

Observed data in the study watersheds were typically collected through grab samples collected on a monthly or bimonthly basis (at best). Because it is not practical to expect such data to exactly match an average simulated value on a specific day, other methods of comparison are needed. The strongest method of comparison is the use of the minimum and maximum simulated values – the observed data should fall roughly within the range of values simulated near the date of observed data collection. Other parameters considered were violation rate, averages, medians, geometric means, etc.

6.2.2.1. Water Quality Calibration and Validation for Shenandoah River study area watersheds

Calibration

Water quality model calibration was performed for Borden Marsh Run, Crooked Run, Happy Creek, Long Branch, Manassas Run, Stephens Run, West Run, and Willow Brook for the period of January 1, 2009 to December 31, 2013 . The goodness-of-fit statistics for the validation runs are listed in Table 6.12 through Table 6.17. Based on the goodness-of-fit parameter values and the visual comparisons, validations for Borden Marsh Run, Crooked Run, Long Branch, Stephens Run, West Run, and Willow Brook were considered acceptable. Graphical comparisons are included in Appendix C.

Initial model predictions of *E. coli* concentrations were high for Borden Marsh Run. In order to calibrate the simulation to the observed data, a number of parameters were changed to follow watershed-wide model adjustments made while calibrating other impairments. Such parameters included livestock stream access, peak waterfowl presence, and fecal coliform production rates for beef cattle and humans. The final goodness-of-fit measures for the calibration at the monitoring station are listed in Table 6.4. Based on the goodness-of-fit parameter values and the visual comparison (Appendix C), the water quality calibration was considered acceptable.

Table 6.4. Water quality calibration statistics for the Borden Marsh Run at station 1BBMR000.20.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Maximum Criterion Violation Rate (%)
Observed	163	361	200	48
Simulated	163	317	258	40

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Initial model predictions of *E. coli* concentration were very high for Crooked Run. Cattle direct deposition was adjusted during the calibration process. Once this adjustment was made the bacteria predictions from HSPF acceptably matched the simulated data. The final goodness-of-fit measures for the calibration at the monitoring station are listed in Table 6.5. Based on the goodness-of-fit parameter values and the visual comparison (Appendix C), the water quality calibration was considered acceptable.

Table 6.5. Water quality calibration statistics for Crooked Run at station 1BCRO002.75.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Maximum Criterion Violation Rate (%)
Observed	72	133	50	14
Simulated	83	157	123	15

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Initial model predictions of *E. coli* were high for Happy Creek. Multiple parameters were adjusted during calibration, these included the wildlife and livestock direct deposition. Once these adjustments were made the bacteria predictions from HSPF acceptably matched the simulated data. The final goodness-of-fit measures for the calibration at the monitoring station are listed in Table 6.6. Based on the goodness-of-fit parameter values and the visual comparison (Appendix C), the water quality calibration was considered acceptable.

Table 6.6. Water quality calibration statistics for Happy Creek at stations 1BHPY001.29 and 1BHPY002.67.

Station		Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Maximum Criterion Violation Rate (%)
1BHPY001.29	Observed	103	248	63	33
	Simulated	119	154	139	24
1BHPY002.67	Observed	44	108	25	10
	Simulated	107	152	159	22

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Initial model predictions of *E. coli* were high for Long Branch following watershed-wide model adjustments made while calibrating other impairments. Such parameters included livestock stream access and fecal coliform production rates for beef cattle and humans. The final goodness-of-fit measures for the calibration at the monitoring station are listed in Table 6.7. Based on the goodness-of-fit parameter values and the visual comparison (Appendix C), the water quality calibration was considered acceptable.

Table 6.7. Water quality calibration statistics for Long Branch at station 1BLNG000.24.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Maximum Criterion Violation Rate (%)
Observed	102	292	100	24
Simulated	122	460	180	27

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Initial model predictions of *E. coli* concentration were slightly high for Manassas Run. Livestock direct deposition was adjusted during the calibration process, as were fecal coliform production rates for beef cattle, and waterfowl population peaks were removed throughout the watershed to reflect resident populations. Once these adjustments were made, the bacteria predictions from HSPF acceptably matched the simulated data. The final goodness-of-fit measures for the calibration at the monitoring station are listed in Table 6.8. Based on the goodness-of-fit parameter values and the visual comparison (Appendix C), the water quality calibration was considered acceptable.

Table 6.8. Water quality calibration statistics for Manassas Run at station 1BMAN002.55.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Maximum Criterion Violation Rate (%)
Observed	69	234	38	15
Simulated	107	157	142	21

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Initial model predictions of *E. coli* were high for Stephens Run. Livestock direct deposition was adjusted during calibration. Once these adjustments were made, the bacteria predictions from HSPF acceptably matched the simulated data. The final goodness-of-fit measures for the calibration at the monitoring station are listed in Table 6.9. Based on the goodness-of-fit parameter values and the visual comparison (Appendix C), the water quality calibration was considered acceptable.

Table 6.9. Water quality calibration statistics for Stephens Run at station 1BSTV000.20.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Maximum Criterion Violation Rate (%)
Observed	46	93	25	12
Simulated	68	131	101	13

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Initial model predictions of *E. coli* were slightly high for West Run. Livestock direct deposition was adjusted during the calibration process. Once this adjustment was made the bacteria predictions from HSPF acceptably matched the simulated data. The final goodness-of-fit measures for the calibration at the monitoring station are listed in Table 6.10. Based on the goodness-of-fit parameter values and the visual comparison (Appendix C), the water quality calibration was considered acceptable.

Table 6.10. Water quality calibration statistics for West Run at station 1BWST000.20.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Maximum Criterion Violation Rate (%)
Observed	80	180	75	23
Simulated	107	207	161	23

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Initial model predictions of *E. coli* were slightly high for Willow Brook. Livestock direct deposition was adjusted during the calibration process. Once this adjustment was made the bacteria predictions from HSPF acceptably matched the simulated data. The final goodness-of-fit measures for the calibration at the monitoring station are listed in Table 6.11. Based on the goodness-of-fit parameter values and the visual comparison (Appendix C), the water quality calibration was considered acceptable.

Table 6.11. Water quality calibration statistics for Willow Brook at station 1BWLO000.71.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Maximum Criterion Violation Rate (%)
Observed	131	256	125	24
Simulated	130	248	184	32

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Validation

Validation was performed for Borden Marsh Run, Crooked Run, Long Branch, Stephens Run, West Run, and Willow Brook at stations 1BBMR000.20, 1BCRO002.75, 1BLNG000.24, 1BSTV000.20, 1BWST000.20, and 1BWLO000.71 for the period (January 1, 2003 to December 31, 2008) to confirm the calibrated input parameters were appropriate. The goodness-of-fit statistics for the validation runs are listed in Table 6.12 through Table 6.17. Based on the goodness-of-fit parameter values and the visual comparisons, validations for Borden Marsh Run, Crooked Run, Long Branch, Stephens Run, West Run, and Willow Brook were considered acceptable. Graphical comparisons are included in Appendix C.

Table 6.12. Summarized goodness-of-fit measures for simulated and observed fecal coliform concentrations for the validation period for Borden Marsh Run at station 1BBMR000.20.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Maximum Criterion Violation Rate (%)
Observed	155	235	175	45
Simulated	162	258	180	40

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Table 6.13. Summarized goodness-of-fit measures for simulated and observed fecal coliform concentrations for the validation period for Crooked Run at station 1BCRO002.75.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Maximum Criterion Violation Rate (%)
Observed	127	270	98	32
Simulated	86	140	129	16

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Table 6.14. Summarized goodness-of-fit measures for simulated and observed fecal coliform concentrations for the validation period for Long Branch at station 1BLNG000.24.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Maximum Criterion Violation Rate (%)
Observed	123	359	100	42
Simulated	122	273	280	31

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Table 6.15. Summarized goodness-of-fit measures for simulated and observed fecal coliform concentrations for the validation period for Stephens Run at station 1BSTV000.20.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Maximum Criterion Violation Rate (%)
Observed	71	183	50	17
Simulated	68	134	108	13

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Table 6.16. Summarized goodness-of-fit measures for simulated and observed fecal coliform concentrations for the validation period for West Run at station 1BWST000.20.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Maximum Criterion Violation Rate (%)
Observed	58	125	25	10
Simulated	107	183	185	28

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Table 6.17. Summarized goodness-of-fit measures for simulated and observed fecal coliform concentrations for the validation period for Willow Brook at station 1BWLO000.71.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Maximum Criterion Violation Rate (%)
Observed	447	685	450	64
Simulated	129	190	233	34

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Chapter 7: Modeling Process for Sediment TMDL Development

A key component in developing a TMDL is establishing the relationship between pollutant loadings (both point and nonpoint) and in-stream water quality conditions. Once this relationship is developed, management options for reducing pollutant loadings to streams can be assessed. In developing a TMDL, it is critical to understand the processes that affect the fate and transport of the pollutant(s) and that cause the impairment of the water body of concern. Pollutant transport to water bodies is evaluated using a variety of tools, including monitoring, geographic information systems (GIS), and computer simulation models. In the development of the sediment TMDL for the Happy Creek watershed, the relationship between pollutant sources and pollutant loading to the stream was defined by land uses and areas assessed from the NASS 2012 cropland data layer, together with non-land based loads and simulated output from a computer watershed loading model. The modeling process, input data requirements, and TMDL load calculation procedures are discussed in this chapter.

7.1. *Model Selection*

The model selected for development of the sediment TMDL in the Happy Creek watershed was the Generalized Watershed Loading Functions (GWLF2010) model, originally developed by Haith et al. (1992), with modifications by Evans et al. (2001), Yagow et al. (2002), and Yagow and Hession (2007). The model was run in metric units and converted to English units for this report.

The loading functions upon which the GWLF model is based are compromises between the empiricism of export coefficients and the complexity of process-based simulation models. GWLF is a continuous simulation spatially-lumped parameter model that operates on a daily time step. The model estimates runoff, sediment, and dissolved and attached nitrogen and phosphorus loads delivered to streams from complex watersheds with a combination of point and non-point sources of pollution. The model considers flow inputs from both surface runoff and groundwater. The hydrology in the model is simulated with a daily water balance procedure that considers different types of storages within the system. The GWLF model was originally developed for use in ungaged watersheds. Although one study recommends hydrologic calibration to improve runoff simulation estimates (Dai et al., 2000), absence of observable flow in the many comparison watersheds in this study led to the decision to simulate loads in a non-calibrated mode.

GWLF uses three input files for weather, transport, and nutrient data. The weather file contains daily temperature and precipitation for the period of simulation. The transport file contains input data primarily related to hydrology and sediment transport, while the nutrient file contains primarily nutrient values for the various land uses, point sources, and septic system types. The Penn State Visual Basic™ version of GWLF with modifications for use with ArcView was the starting point for additional modifications (Evans et al., 2001). The following modifications related to sediment were made to the Penn State version of the GWLF model, as incorporated in their ArcView interface for the model, AvGWLF v. 3.2:

- Urban sediment buildup was added as a variable input.
- Urban sediment washoff from impervious areas was added to total sediment load.
- Formulas for calculating monthly sediment yield by land use were corrected.
- Mean channel depth was added as a variable to the streambank erosion calculation.

The GWLF2006 version of GWLF (Yagow and Hession, 2007) was used in previous TMDL studies. The GWLF2006 version includes a correction to the flow accumulation calculation in the channel erosion routine that was implemented in December 2005 (VADEQ, 2005). This version also includes modifications from Schneiderman et al. (2002) to include an unsaturated zone leakage coefficient, to remove the annual boundary for transported sediment distribution, and to add in missing bounds for the calculation of erosivity using Richardson equations which were intended to have minimum and maximum bounds on daily calculations. These minimum and maximum bounds were not included in GWLF 2.0, and have been added to keep calculations within physically expected bounds. Delivered loads were also recoded as a function of transported, instead of detached, sediment. The current GWLF2010 version restored the original annual boundary for transported sediment distribution to correct a minor calculation error.

Erosion is generated using a modification of the Universal Soil Loss Equation. Sediment supply uses a delivery ratio together with the erosion estimates, and sediment transport takes into consideration the transport capacity of the runoff. Stream bank and channel erosion was calculated using an algorithm by Evans et al. (2003) as incorporated in the AVGWLF version (Evans et al., 2001) of the GWLF model and corrected for a flow accumulation coding error (VADEQ, 2005).

Since simulated sediment loads were required from the five comparison watersheds as well as from the Happy Creek sub-watersheds, model input data were created for each of the five comparison watersheds, and for all of the Happy Creek sub-watersheds. Model development for all watersheds was performed by assessing the sources of sediment in each watershed, evaluating the necessary parameters for modeling loads, and finally applying the model and procedures for calculating loads.

Since some of the headwater watersheds are nested within downstream watersheds, the land segments were simulated uniquely, so that the land areas and associated loads do not overlap. Total loads to downstream segments were summed from all upstream segments, with adjustments to sub-watershed loads to account for differential delivery factors (representative of in-stream attenuation and a function of cumulative upstream watershed area). Also, since channel erosion is calculated as a power function of cumulative upstream area, channel erosion for individual sub-watersheds that received flow from upstream sub-watersheds was a subtractive process. Channel erosion for a downstream sub-watershed was calculated as the channel erosion from the cumulative watershed at its outlet minus the channel erosion calculated for upstream sub-watersheds.

The Happy Creek impaired segments and the modeled sub-watersheds are shown in Figure 7.1.

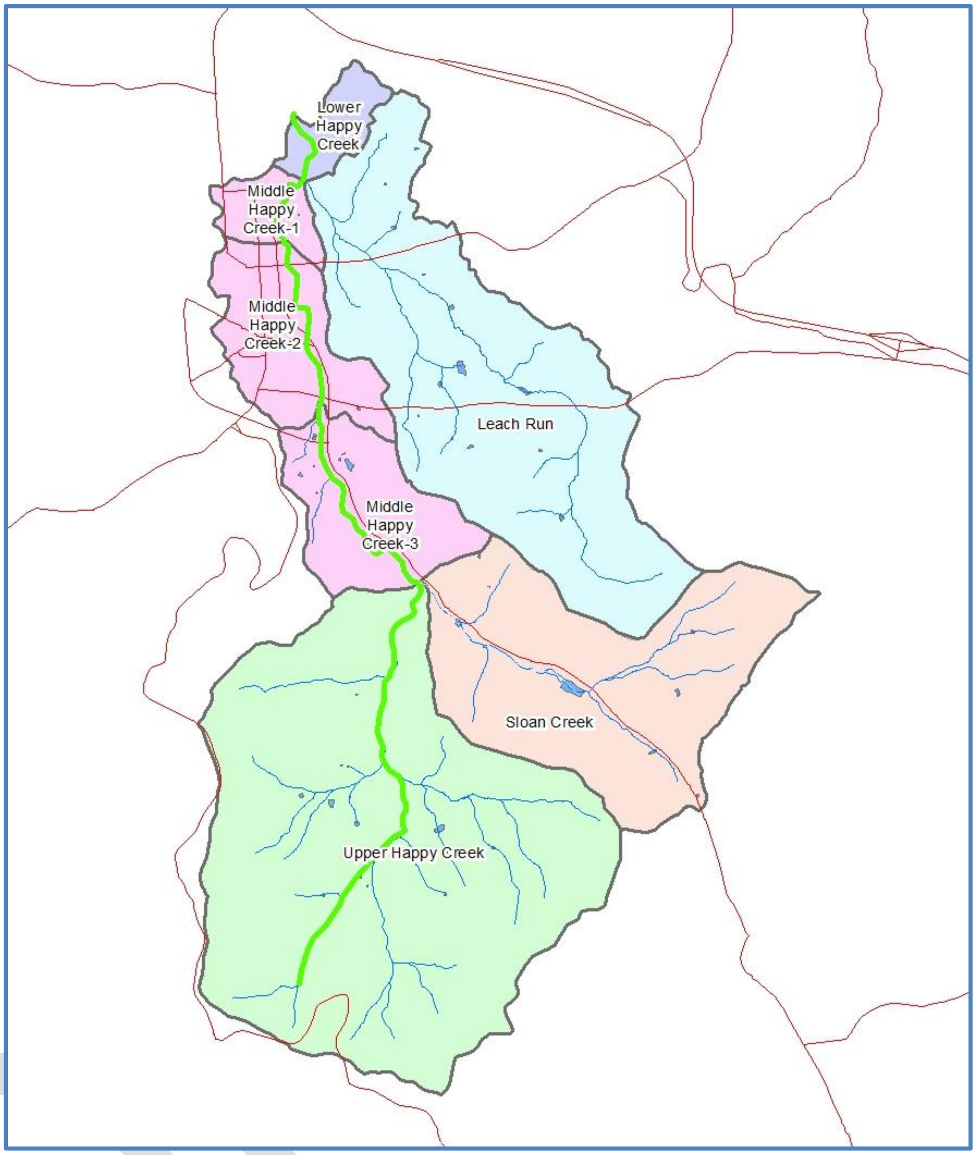

Figure 7.1. Happy Creek and Modeled Sub-watersheds

7.2. ***Input Data Requirements***

7.2.1. **Climate Data**

The climate in Happy Creek watershed was characterized by meteorological observations from the National Weather Service Cooperative Station 443229 in Front Royal. For the comparison watersheds, the Fiery Run (FIR) and Manassas Run (MAN) watersheds also used the Front Royal data, while Mill Creek watershed (MIL) used data from station 442663 (Edinburg), and Rose River watershed (ROE) used data from station

440720 (Big Meadows). The period of record used for sediment TMDL modeling was a seventeen-year period from January 1997 through December 2013, with the preceding 9 months of data used to initialize storage parameters. The locations of the various NCDC stations are shown in relationship to the Happy Creek and the comparison watersheds in Figure 7.2.

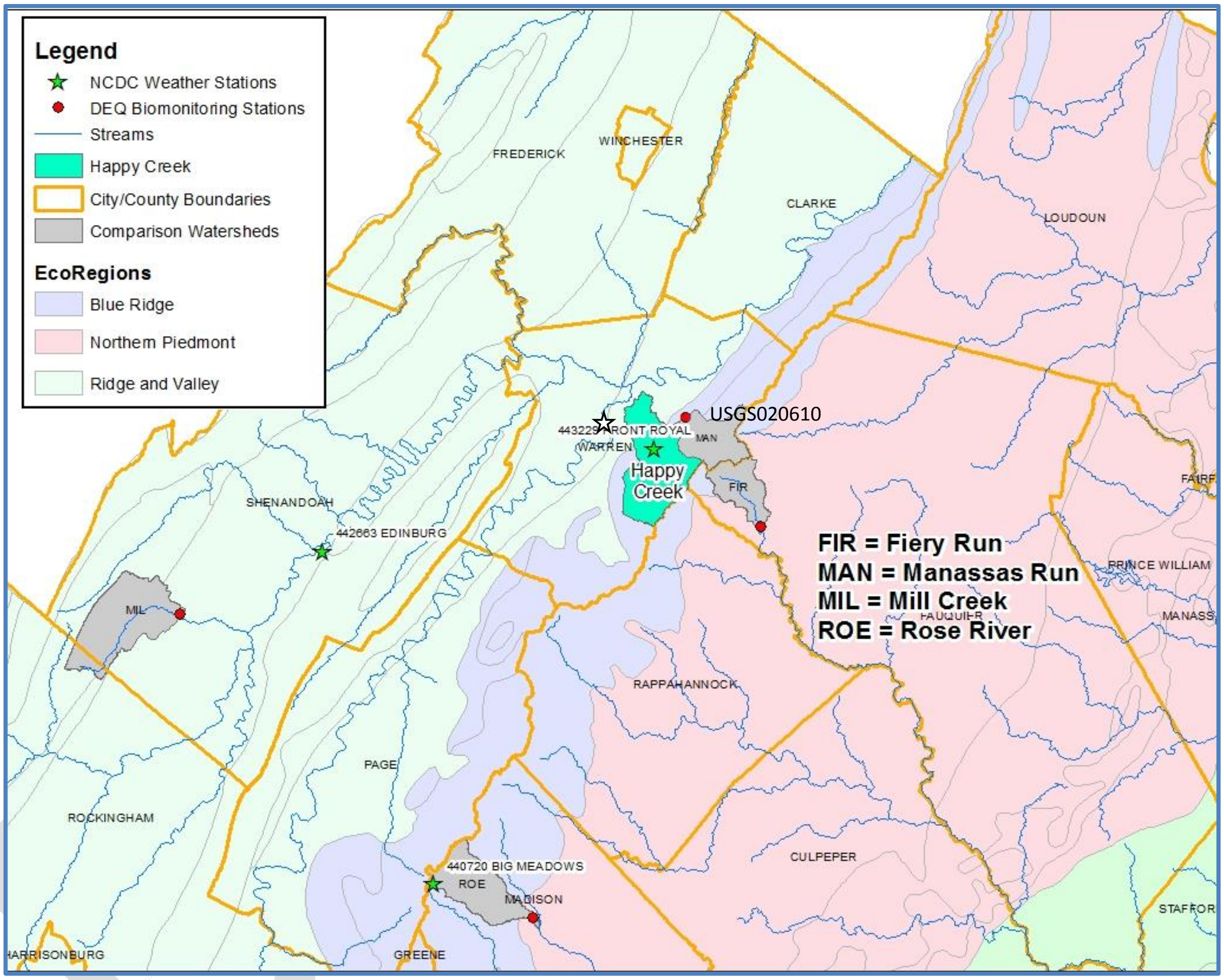

Figure 7.2. Location of Weather Stations

7.2.2. **Existing Land Use**

Modeled land uses for the Happy Creek and the comparison watersheds were derived from the USDA National Agricultural Statistics Service digital cropland data layer for 2012, as discussed in Section 2.5. The NASS categories were consolidated into general land use categories of Row Crop, Hay, Pasture, Forest, and various “developed urban” categories, as shown in Table 7.1.

Table 7.1. NASS Land Use Group Distributions

		RowCrop	Hay	Pasture	Forest	Barren	Pervious LDI	LDI	MDI	HDI	Transp	Water	Total
		Area in acres											
Happy Creek Watershed													
Lower Happy Creek	HPY1	0.0	25.2	16.8	192.9	0.2	18.8	16.6	0.9	0.0	0.0	0.4	271.8
Leach Run	HPY2	7.3	332.3	221.5	2042.7	5.3	394.5	452.7	73.7	4.0	0.0	3.1	3,537.2
Middle Happy Creek-1	HPY3	0.0	7.9	5.3	25.9	1.8	50.1	107.1	54.4	15.3	7.6	0.0	275.5
Middle Happy Creek-2	HPY4	0.0	9.1	6.1	25.2	6.5	167.4	330.8	182.9	116.7	24.0	0.0	868.7
Middle Happy Creek-3	HPY5	9.9	72.5	48.4	557.7	1.0	142.7	56.7	22.0	6.9	13.6	1.8	933.2
Sloan Creek	HPY6	34.3	272.9	181.9	1579.1	0.9	409.5	57.9	4.4	0.0	25.5	2.0	2,568.5
Upper Happy Creek	HPY7	12.7	243.2	162.2	4952.9	0.4	274.4	32.7	7.3	0.2	0.0	3.8	5,689.8
Happy Creek Total		**64.3**	**963.2**	**642.1**	**9376.4**	**16.1**	**1457.5**	**1054.5**	**345.7**	**143.1**	**70.7**	**11.1**	**14,144.6**
Comparison Watersheds													
Fiery Run	FIR	22.0	459.2	306.2	5045.5	0.0	81.9	0.4	0.0	0.0	0.0	0.0	5,915.3
Manassas Run	MAN	17.0	298.1	198.7	5429.4	2.2	868.1	213.1	8.7	0.9	0.0	0.0	7,036.2
Mill Creek	MIL	80.7	1530.6	1020.4	12164.1	0.7	630.5	59.8	7.3	0.2	0.0	0.0	15,494.3
Rose River	ROE	15.5	190.1	126.7	9215.0	0.3	382.2	26.7	6.1	0.4	0.0	0.0	9,962.9

LDI = low intensity developed; MDI = medium intensity developed; HDI = high intensity developed

The Row Crop category was subdivided into hi-till and low-till categories based on Conservation Tillage Information Center (CTIC) data as incorporated in the 2006 Virginia Statewide NPS Watershed Assessment (Yagow and Hession, 2007). The Hay and Pasture acreages were combined and reassigned in an 85/15 ratio based on an assessment by local conservation personnel. From the Pasture category, the “riparian”, and “animal feeding operation” land uses were calculated as 0.00374 and 0.00044 times the total Pasture area, respectively, as estimated from proportions within the Chesapeake Bay Watershed Model (CBWM) land-river segment PS5_5200_4380. The remaining Pasture area was sub-divided into 30% “good”, 30% “fair”, and 40% “poor” pasture land uses, based on an assessment by local conservation personnel. A “harvested forest” land use was created as 1% of the Forest category, similar to procedures used in the CBWM (USEPA, 2010). The “barren” category area was re-assigned as 1% of all the developed land use categories (barren, LDI, MDI, HDI, and Transportation) for Happy Creek, as well as for all the comparison watersheds, and subtracted from the “Pervious_LDI” land use. The “developed” categories were sub-divided into pervious and impervious portions, with “urban open space” assigned to the pervious portion of the “low intensity developed” land use. Impervious percentages of 20%, 50%, and 80% were used, respectively, for the low intensity, medium intensity and high intensity developed areas and 33.3% for the transportation areas. The simulated land uses and their derivations are summarized in Table 7.2, while detailed distributions are included in Appendix D.

Table 7.2. Modeled Land Use Categories

NASS Groups	NASS Land Uses	% Impervious	Modeled Land Use Categories
Row Crop	Corn, sorghum, soybeans, winter wheat, etc.	0	Hi-till cropland
			Lo-till cropland
Hay	Alfalfa, other hays	0	Hay
Pasture	Pasture/grass, shrubland, grassland herbaceous	0	Good pasture
			Fair pasture
			Poor Pasture
			Riparian pasture
			Animal feeding operation
Forest	Deciduous forest, evergreen forest, mixed forest, herbaceous	0	Forest
			Harvested forest
Barren	Barren	0	Barren
Pervious_LDI	Urban open space	0	Pervious LDI
LDI	Developed, low intensity	20	Impervious LDI
			Pervious LDI
MDI	Developed, medium intensity	50	Impervious MDI
			Pervious MDI
HDI	Developed, high intensity	80	Impervious MDI
			Pervious MDI
Transp	Transportation	33	Impervious HDI
			Pervious HDI

Each land use within a sub-watershed formed a hydrologic response unit (HRU). Model parameters were then calculated for each HRU using GIS analysis to reflect the variability in topographic and soil characteristics across the watershed. A description of model parameters follows in section 7.4.

7.3. *Future Land Use*

A future land use scenario was created using the same land use categories as for the existing scenario. Future land use change was assessed from the Warren County Comprehensive Plan's Urban Development Areas (UDAs) which were developed to all fall within the Town of Front Royal's boundaries. Expected future growth (FG) based on this analysis would fall only within the Leach Run, Middle Happy Creek 2, and Middle Happy Creek 3 sub-watersheds. A cross-tabulation from the spatial UDA layer was made with the NASS cropland data layer within Happy Creek to assess which land uses would be subject to change in each sub-watershed, as shown in Table 7.3. There were three UDA categories, and for the purposes of this analysis, the two residential categories were combined into one. Residential land use change was predicted to primarily occur in the Leach Run watershed. Since there were large areas of pasture/hay, forest, and pervious_LDI land use categories falling within the UDAs, for this analysis, it was assumed that only 50% of those areas would be developed in the near future. All land falling within the commercial UDA zones was assumed to change to high intensity developed purposes, unless they were already in that land use. All land falling within the residential UDA zones were assumed to incrementally increase in developed intensity. Note that the areas shown in the table are in metric units, but the totals at the bottom are shown in acres.

Table 7.3. Future Land Use Change Assessment Summary

Land Use	Estate Residential District	Suburban Residential District	Community Business District	Fraction of UDA Residential Zoned Acreage Changed in FG Scenario	Land Use Changes			
	R-E	R-S	C-1		Current Residential Area (ha)	Future Land Use	Current Commercial Area (ha)	Future Land Use
	Area in hectares (ha)							
2 - Leach Run						74.50		4.39
Row Crop		0.48		1	0.48	LDI		
Pasture/Hay	22.74	32.86	0.04	0.5	27.80	LDI	0.04	HDI
Water		0.20		0	0.00	No change		
Pervious_Urban	0.20	9.74	0.08	0.5	4.97	LDI	0.08	HDI
LDI		2.07	0.02	1	2.07	MDI	0.02	HDI
MDI		0.10		1	0.10	No change		
Forest	8.22	69.93	4.25	0.5	39.07	LDI	4.25	HDI
4 - Middle Happy Creek 2						0.00		2.69
Pervious_Urban			0.18				0.18	HDI
LDI			0.92				0.92	HDI
MDI			1.60				1.60	HDI
HDI			1.96					No change
5 - Middle Happy Creek 3						0.00		9.74
Pasture/Hay			0.04				0.04	HDI
Pervious_Urban			4.65				4.65	HDI
LDI			2.21				2.21	HDI
MDI			2.83				2.83	HDI
HDI			5.75					No change
Transportation			0.34					No change
Total Area Changed					184.08	acres	41.56	acres

Detailed tables of the land use distribution for the future land use scenario are included in Appendix D.

7.4. *GWLF Parameter Evaluation*

All parameters were evaluated in a consistent manner for all watersheds in order to ensure their comparability. All GWLF parameter values were evaluated from a combination of GWLF user manual guidance (Haith et al., 1992), AVGWLF procedures (Evans et al., 2001), procedures developed during the 2006 statewide NPS pollution assessment (Yagow and Hession, 2007), and best professional judgment.

Hydrologic and sediment parameters are all included in GWLF's transport input file, with the exception of urban sediment buildup rates, which are in the nutrient input file. Nutrient parameters are all included in GWLF's nutrient input file. Descriptions of each of the hydrologic, sediment, and nutrient parameters are listed below according to whether the parameters were related to the overall watershed, to the month of the year, or to individual land uses. The GWLF parameter values used for each of the Happy Creek and comparison watersheds are detailed in Appendix F.

7.4.1. **Hydrology Parameters**

Watershed-Related Parameter Descriptions

- Unsaturated Soil Moisture Capacity (SMC, cm): The amount of moisture in the root zone, evaluated as a function of the area-weighted soil type attribute - available water capacity.
- Recession coefficient (day^{-1}): The recession coefficient is a measure of the rate at which streamflow recedes following the cessation of a storm, and is approximated by averaging the ratios of streamflow on any given day to that on the following day during a wide range of weather conditions, all during the recession limb of each storm's hydrograph. This parameter was evaluated using the following relationship from Lee et al. (2000): RecCoeff = 0.045 + 1.13/(0.306 + Area in square kilometers)
- Seepage coefficient: The seepage coefficient represents the fraction of flow lost as seepage to deep storage.
- Leakage coefficient: The leakage coefficient represents the fraction of infiltration that bypasses the unsaturated zone through macro-pore flow. An increase in this coefficient, initially set to zero, decreases ET losses and increases baseflow.

The following parameters were initialized by running the model for a 9-month period prior to the period used for load calculation:

- Initial unsaturated storage (cm): Initial depth of water stored in the unsaturated (surface) zone.
- Initial saturated storage (cm): Initial depth of water stored in the saturated zone.
- Initial snow (cm): Initial amount of snow on the ground at the beginning of the simulation.
- Antecedent Rainfall for each of 5 previous days (cm): The amount of rainfall on each of the five days preceeding the current day.

Month-Related Parameter Descriptions

- Month: Months were ordered, starting with April and ending with March – in keeping with the design of the GWLF model.
- ET_CV: Composite evapotranspiration cover coefficient, calculated as an area-weighted average from land uses within each watershed.
- Hours per Day: Mean number of daylight hours.
- Erosion Coefficient: This is a regional coefficient used in Richardson's equation for calculating daily rainfall erosivity. Each region is assigned separate coefficients for the months October-March, and for April-September.

Land Use-Related Parameter Descriptions

- Curve Number: The SCS curve number (CN) is used in calculating runoff associated with a daily rainfall event, evaluated using SCS TR-55 guidance (USDA-SCS, 1986).

7.4.2. **Sediment Parameters**

Watershed-Related Parameter Descriptions

- Sediment delivery ratio: The fraction of erosion – detached sediment – that is transported or delivered to the edge of the stream, calculated as an inverse function of watershed size (Evans et al., 2001).

Land Use-Related Parameter Descriptions

- USLE K-factor: The soil erodibility factor was calculated as an area-weighted average of all component soil types.
- USLE LS-factor: This factor is calculated from slope and slope length measurements by land use. Slope is evaluated by GIS analysis, and slope length is calculated as an inverse function of slope.

- USLE C-factor: The vegetative cover factor for each land use was evaluated following GWLF manual guidance, Wischmeier and Smith (1978), and Hession et al. (1997); and then adjusted after consultation with local NRCS personnel.
- Daily sediment buildup rate on impervious surfaces: The daily amount of dry deposition deposited from the air on impervious surfaces on days without rainfall, assigned using GWLF manual guidance.

Streambank Erosion Parameter Descriptions (Evans et al., 2003)

- % Developed land: percentage of the watershed with urban-related land uses – defined as all land in MDI and HDI land uses, as well as the impervious portions of LDI.
- Animal density: calculated as the number of beef and dairy 1000-lb equivalent animal units (AU) divided by the watershed area in acres.
- Curve Number: area-weighted average value for the watershed.
- K Factor: area-weighted USLE soil erodibility factor for the watershed.
- Slope: mean percent slope for the watershed.
- Stream length: calculated as the total stream length of natural perennial stream channels, in meters.
- Mean channel depth (m): calculated from relationships developed either by the Chesapeake Bay Program or by USDA-NRCS by physiographic region, of the general form: $y = a * A^b$, where y = mean channel depth in ft, A = drainage area in square miles, and "a" and "b" are regression coefficients (USDA-NRCS, 2005). The mean channel depth was then converted from feet to meters.

7.5. *Supplemental Post-Model Processing*

After modeling was performed on individual and cumulative sub-watersheds, model output was post-processed in a Microsoft Excel™ spreadsheet to summarize the modeling results and to account for existing levels of BMPs already implemented within each watershed.

The extent and effect of existing agricultural BMPs in the TMDL watersheds were based on data extracted from Virginia DCR's online agricultural BMP database for the sixth-order watershed that comprises Happy Creek watershed (PS48).

Sediment

The extent and effect of existing agricultural BMPs on the comparison watersheds were based on the pass-through fractions of the sediment load from each land use in each HUP as developed by Virginia DCR previously for the Virginia 2006 Statewide NPS Pollution Assessment (Yagow and Hession, 2007).

Modeled sediment loads within each land use category were then multiplied by their respective pass-through fractions to simulate the reduced loads resulting from existing BMPs.

Sediment BMPs are required on harvested forest lands and on disturbed lands subject to Erosion and Sediment (E&S) regulations. A sediment efficiency of 60% was used for BMPs on harvested forest land, while sediment reductions from disturbed land was assumed to be subject to E&S permits with a sediment efficiency of 40% (USEPA, 2010). Existing BMPs were assumed to be achieving only half of those potential efficiencies.

7.6. *Representation of Sediment Sources*

Sediment is generated in the Happy Creek watershed through the processes of surface runoff, in-channel disturbances, and streambank and channel erosion, as well as from natural background contributions and permitted sources. Sediment generation is accelerated through human-induced land-disturbing activities related to a variety of agricultural, forestry, mining, transportation, and residential land uses.

Permitted sediment dischargers in Happy Creek currently include only stormwater discharges. Stormwater discharges include construction permits regulated through Virginia's Erosion and Sediment Control Program and urban stormwater runoff from MS4, municipal, industrial and general permits.

7.6.1. **Surface Runoff**

During runoff events, sediment loading occurs from both pervious and impervious surfaces around the watershed. For pervious areas, soil is detached by rainfall impact or shear stresses created by overland flow and transported by overland flow to nearby streams. This process is influenced by vegetative cover, soil erodibility, slope, slope length, rainfall intensity and duration, and land management practices. During periods without rainfall, dirt, dust and fine sediment build up on impervious areas through dry deposition, which is then subject to washoff during rainfall events. Pervious area sediment loads were modeled using a modified USLE erosion detachment algorithm, monthly transport capacity calculations, and a sediment delivery ratio in the GWLF model to calculate loads at the watershed outlet. Impervious area sediment loads were modeled in the GWLF model using an exponential buildup-washoff algorithm.

7.6.2. **Channel and Streambank Erosion**

Streambank erosion was modeled within the GWLF model using a modification of the routine included in the AVGWLF version of the GWLF model (Evans et al., 2001). This routine calculates average annual streambank erosion as a function of percent developed land, average area-weighted curve number (CN) and K-factors, watershed animal density, average slope, streamflow volume, mean channel depth, and total stream length in the watershed. Livestock population, which figures into animal density, was estimated based on a stocking density of 0.2026 animal units per acre of available pasture (AU/acre).

7.6.3. **Industrial Stormwater**

Currently, there is one (1) active Industrial Storm Water General Permits (ISWGPs) in the Happy Creek watershed. Current sediment load for the facility was simulated as part of the urban pervious and impervious land use categories. Permitted WLA loads for each facility were calculated as the permitted area of the facility times the permitted average TSS concentration of 100 mg/L times the average annual runoff (simulated for low intensity developed areas), as shown in Table 7.4.

Table 7.4. Industrial Stormwater General Permit (ISWGP) WLA Loads

Facility Name	VPDES Permit Number	Source Type	Receiving Stream	Area (acres)	Permitted Average TSS Concentration (mg/L)	Average Annual Runoff (in/yr)	TSS WLA (tons/yr)
Zuckerman Metals, Inc.	VAR050852	ISWGP	Happy Creek	11.16	100	19.92	2.52

Load = X acres * Y mg/L * Z in/yr * 102,801.6 L/acre-inch * 1 lb/453,600 mg * 1 ton/2000 lbs = X * Y * Z * 0.000113317 tons/yr

7.6.4. **Construction Stormwater**

Although currently there are no active construction stormwater permits in Happy Creek, loads from this intermittent activity are expected to occur periodically. To account for periodic construction stormwater loads, "barren" land use was estimated as 1% of all developed land uses, except the pervious_LDI category which often times includes urban recreational areas, and loads simulated from these areas used to represent the load from construction stormwater. Aggregated construction WLA loads for each sub-watershed were calculated as the permitted area times the permitted average TSS concentration of 60 mg/L times the simulated average annual runoff for the "barren" land use for "future" conditions, as shown in Table 7.5.

Table 7.5. Aggregated Construction WLA Loads

Receiving Stream	Area (acres)	Permitted Average TSS Concentration (mg/L)	Average Annual Runoff (in/yr)	Aggregated TSS WLA Load (tons/yr)
Lower Happy Creek	0.18	60	7.74	0.01
Leach Run	0.22	60	7.74	0.01
Middle Happy Creek-1	11.07	60	7.74	0.58
Middle Happy Creek-2	0.00	60	7.74	0.00
Middle Happy Creek-3	0.00	60	7.74	0.00
Sloan Creek	0.94	60	7.74	0.05
Upper Happy Creek	0.40	60	7.74	0.02

7.6.5. **Municipal Separate Storm Sewer Systems (MS4)**

There are no MS4 permits in Happy Creek watershed.

7.6.6. **Other Permitted Sources (VPDES and General Permits)**

There are no general discharge permits for single-family homes in Happy Creek watershed.

7.7. ***Accounting for Critical Conditions and Seasonal Variations***

7.7.1. **Selection of Representative Modeling Period**

Selection of the modeling period was based on the availability of daily weather data and the need to represent variability in weather patterns over time in the watershed. A long period of weather inputs was selected to represent long-term variability in the watershed. The model was run using a weather time series from April 1996 through December 2013, with the first 9 months used as an initialization period for internal storages within the model. The remaining 17-year period was used to calculate average annual sediment loads in all watersheds.

7.7.2. **Critical Conditions**

The GWLF model is a continuous simulation model that uses daily time steps for weather data and water balance calculations. The period of rainfall selected for modeling was chosen as a multi-year period that was representative of typical weather conditions for the area, and included "dry", "normal" and "wet" years. The model, therefore, incorporated the variable inputs needed to represent critical conditions during low flow – generally associated with point source loads – and critical conditions during high flow – generally associated with nonpoint source loads.

7.7.3. **Seasonal Variability**

The GWLF model used for this analysis considered seasonal variation through a number of mechanisms. Daily time steps were used for weather data and water balance calculations. The model also used monthly-variable parameter inputs for evapo-transpiration cover coefficients, daylight hours/day, and rainfall erosivity coefficients for user-specified growing season months.

7.8. ***Existing Sediment Loads***

Existing sediment loads were simulated for all individual land uses with the calibrated GWLF model, as discussed previously. The resulting loads in Happy Creek are given in

Table 7.6, together with aggregate unit-area loads (tons/ac) for each land use.

Table 7.6. Existing Sediment Loads in Happy Creek Watershed

Land Use/Source Categories	Lower Happy Creek	Leach Run	Middle Happy Creek-1	Middle Happy Creek-2	Middle Happy Creek-3	Sloan Creek	Upper Happy Creek	Happy Creek Total	Unit-Area Load
	Sediment Load (tons/yr)								(tons/ac)
HiTill Rowcrop (hit)	0.0	11.3	0.0	0.0	20.9	80.4	23.5	136.1	7.06
LoTill Rowcrop (lot)	0.0	6.2	0.0	0.0	11.3	44.7	13.1	75.3	1.67
Pasture (pas_g)	0.4	10.4	0.0	0.4	5.6	17.5	13.8	48.0	0.25
Pasture (pas_f)	1.9	47.7	0.2	1.9	25.3	79.1	62.5	218.5	1.14
Pasture (pas_p)	5.3	134.4	0.5	5.4	71.2	212.9	166.1	595.7	2.33
Riparian pasture (trp)	0.5	10.9	0.0	0.4	5.5	16.6	13.1	47.0	19.60
AFO (afo)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
Hay (hay)	6.3	162.8	0.6	6.4	85.9	264.2	208.9	735.1	0.76
Forest (for)	7.6	82.9	0.7	0.8	35.9	83.4	348.6	559.8	0.06
Harvested forest (hvf)	0.6	6.6	0.1	0.1	2.8	6.4	26.4	43.0	0.46
Transitional (barren)	2.6	46.1	13.8	47.3	22.1	6.9	4.9	143.8	8.90
Pervious LDI (pur_LDI)	8.4	141.0	19.9	83.6	52.8	140.5	83.0	529.1	0.23
Pervious MDI (pur_MDI)	0.0	3.6	3.0	5.0	1.2	0.4	0.8	14.1	0.08
Pervious HDI (pur_HDI)	0.0	0.0	0.3	0.7	0.0	0.0	0.0	1.1	0.04
Pervious TRN (pur_rds)	0.0	0.0	0.4	0.8	3.2	5.5	0.0	9.9	0.21
Impervious LDI (imp_LDI)	0.3	6.4	1.8	5.4	1.0	0.9	0.5	16.2	0.08
Impervious MDI (imp_MDI)	0.2	12.2	10.9	36.2	4.2	0.7	1.3	65.7	0.38
Impervious HDI (imp_HDI)	0.0	0.7	3.1	23.3	1.3	0.0	0.0	28.4	0.25
Impervious TRN (imp_rds)	0.0	0.0	0.5	1.4	0.8	1.2	0.0	3.9	0.17
Channel Erosion	15.6	1.8	4.3	12.8	8.0	1.3	3.9	47.6	
Point Sources	0.0	0.4	3.1	0.3	0.1	0.0	0.0	3.9	
Total Sediment Load	**49.6**	**685.2**	**63.0**	**232.0**	**359.1**	**962.8**	**970.6**	**3,322.3**	

In Tables 7.6 and 7.7, sub-watershed loads were calculated based on the sources contributing from each unique stream segment and its contributing drainage area, exclusive of in-stream contributions received from upstream sub-watersheds. Total loads from all upstream segments are not directly additive to calculate total downstream loads, because differential delivery factors (representative of in-stream attenuation) would apply to smaller upstream areas than to larger downstream watersheds which receive in-stream loads from other stream segments.

7.9. ***Future Sediment Loads***

Future sediment loads were simulated for all land use categories with the GWLF model with permitted sources calculated at their WLA permit limits, as discussed previously. Future sediment loads are the starting loads from which reductions will be required to meet the TMDL. The resulting future sediment loads and unit area loads, shown in Table 7.7, are simulated from assessed future land use changes within defined Urban Development Areas (UDAs).

Table 7.7. Future Sediment Loads in TMDL Watersheds

Land Use/Source Categories	Lower Happy Creek	Leach Run	Middle Happy Creek-1	Middle Happy Creek-2	Middle Happy Creek-3	Sloan Creek	Upper Happy Creek	Happy Creek Total	Unit-Area Load
	Sediment Load (tons/yr)								(tons/ac)
HiTill Rowcrop (hit)	0.0	9.5	0.0	0.0	20.8	80.4	23.5	134.3	6.97
LoTill Rowcrop (lot)	0.0	5.2	0.0	0.0	11.3	44.7	13.1	74.3	1.65
Pasture (pas_g)	0.4	9.1	0.0	0.4	5.6	17.5	13.8	46.7	0.24
Pasture (pas_f)	1.9	41.7	0.2	1.9	25.2	79.1	62.5	212.5	1.11
Pasture (pas_p)	5.3	117.6	0.5	5.4	71.0	212.9	166.1	578.7	2.26
Riparian pasture (trp)	0.5	9.5	0.0	0.4	5.5	16.6	13.1	45.6	19.02
AFO (afo)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
Hay (hay)	6.3	142.4	0.6	6.4	85.6	264.2	208.9	714.4	0.74
Forest (for)	7.6	78.4	0.7	0.8	35.8	83.4	348.6	555.3	0.06
Harvested forest (hvf)	0.6	6.2	0.1	0.1	2.8	6.4	26.4	42.6	0.45
Transitional (barren)	2.6	62.4	13.8	47.4	24.6	6.9	4.9	162.7	10.08
Pervious LDI (pur_LDI)	8.4	164.0	19.9	83.1	48.2	140.5	83.0	547.0	0.24
Pervious MDI (pur_MDI)	0.0	3.9	3.0	4.9	0.8	0.4	0.8	13.9	0.08
Pervious HDI (pur_HDI)	0.0	0.2	0.3	0.7	0.2	0.0	0.0	1.4	0.05
Pervious TRN (pur_rds)	0.0	0.0	0.4	0.8	3.2	5.5	0.0	9.9	0.21
Impervious LDI (imp_LDI)	0.3	8.9	1.8	5.3	0.9	0.9	0.5	18.5	0.09
Impervious MDI (imp_MDI)	0.2	13.0	10.9	35.4	2.9	0.7	1.3	64.4	0.37
Impervious HDI (imp_HDI)	0.0	2.5	3.1	24.6	6.0	0.0	0.0	36.2	0.32
Impervious TRN (imp_rds)	0.0	0.0	0.5	1.4	0.8	1.2	0.0	3.9	0.17
Channel Erosion	17.3	2.1	4.4	12.9	8.4	1.3	3.9	50.2	
Point Sources	0.0	0.4	3.1	0.3	0.1	0.0	0.0	3.9	
Total Sediment Load	**51.4**	**676.8**	**63.1**	**232.2**	**359.8**	**962.8**	**970.6**	**3,316.6**	

Chapter 8: TMDL Allocations

The objective of a TMDL is to allocate allowable loads among different pollutant sources so that the appropriate control actions can be taken to achieve water quality standards (USEPA, 1991).

8.1. *Bacteria TMDLs*

The objective of the bacteria TMDLs for the Shenandoah River tributaries watersheds was to determine what reductions in fecal coliform and *E. coli* loadings from point and nonpoint sources are required to meet state water quality standards. The state water quality standard for *E. coli* used in the development of the TMDL was a calendar-month geometric mean of 126 cfu/100 mL. The TMDL considers all significant sources contributing *E. coli* to the impaired streams. The sources can be separated into nonpoint and point sources. The different sources in the TMDL are defined in the following equation:

$$TMDL = WLA_{total} + LA + MOS \qquad [8.1]$$

Where:

WLA_{total} = waste load allocation (point source contributions, including future growth);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety.

A TMDL accounts for critical conditions, seasonal variations and must include a margin of safety (MOS).

8.1.1. **Accounting for Critical Conditions and Seasonal Variations**

Current EPA regulations [40 CFR 130.7(c)(1)] require TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. Such an approach ensures that TMDLs, when implemented, will not result in violations of the water quality criteria under a wide variety of flow regimes that affect *E. coli* concentrations.

A period of five years was used for allocation modeling. Observed meteorological data from the NCDC Cooperative Weather Stations at Front Royal and Winchester were extracted for 2001, 2002, 2003, 2009, and 2011 and used in the allocation simulations. These particular rainfall years were selected because they incorporate average rainfall, low rainfall, and high rainfall; and the climate during these years caused a wide range of hydrologic events including both low and high flow conditions. The bacteria loading in the model for allocation scenarios was representative of anticipated future conditions.

The continuous simulation model developed for these TMDLs explicitly incorporates the seasonal variations of rainfall and other meteorological parameters, in addition to monthly estimates of fecal coliform loads. By using an hourly time-step in the model, these measures account for the seasonal effects in fecal coliform loading within the watershed.

When developing a bacterial TMDL, the required bacteria load reductions are modeled by decreasing the amount of bacteria running off the land surface that reach the stream or decreasing the amount of bacteria directly deposited in the stream; these reductions are presented in the tables in the following sections. The reductions called for in the following sections indicate the need to decrease the amount of bacteria reaching the stream in order to meet the applicable water quality standard. The reductions shown in these sections are not intended to infer that agricultural producers should reduce their herd size, or limit the use of manures as fertilizer or soil conditioner. Rather, it is assumed that the required reductions from affected agricultural source categories (livestock direct deposit, cropland, etc.) will be accomplished by implementing BMPs like filter strips, stream fencing, and off-stream watering; and that required reductions from residential source categories will be accomplished by repairing aging septic systems, eliminating straight pipe discharges, eliminating sewage spills, and other appropriate measures included in the TMDL Implementation Plan.

The calendar-month geometric mean values used in this report are geometric means of the simulated daily concentrations. Because HSPF was operated with a one-hour time step in this study, 24 hourly concentrations were generated each day. To estimate the calendar-month geometric mean from the hourly HSPF output, the arithmetic mean of the hourly values was computed on a daily basis, and then the geometric mean was calculated from these average daily values.

8.1.2. **Margin of Safety**

A MOS is factored into a TMDL to account for model uncertainty. The MOS can be either explicit, as an additional load reduction requirement, or implicit, which incorporates conservative assumptions within the application of the TMDL model. An implicit MOS was used in these bacteria TMDLs by using conservative estimations of all factors that would affect bacteria loadings in the watershed (e.g., animal numbers, production rates, contributions to the stream). These factors were estimated in such a way as to represent the worst-case scenario; i.e., they describe the worst stream conditions that could exist in the watersheds. Creating TMDLs with conservative estimates ensures that the worst-case scenario has been considered and that no water quality standard violations will occur if the TMDL plan is followed.

8.1.3. **Existing Conditions**

Analysis of the simulation results for the existing conditions in the watershed (Table 8.1) shows that contributions from livestock direct deposits are the primary source of *E. coli* to Borden Marsh Run, Manassas Run, and Willow Brook. Contributions from pasture are the primary source of *E. coli* to Crooked Run, Long Branch, Stephens Run, and West Run. Contributions from permitted sources (including sanitary sewer overflows) and direct deposits by wildlife are the primary sources of *E. coli* to Happy Creek. The results in this table were taken as the average daily contributions for the allocation simulation period, irrespective of the magnitude of the concentration or the flow rate (factors that were considered in the earlier section detailing the source breakdown used in the calibration).

Table 8.1. Relative contributions of different *E. coli* sources to the overall *E. coli* concentration for existing conditions in the Shenandoah River tributaries watersheds.

Source	Relative Daily Contribution by Source							
	Borden Marsh Run	Crooked Run	Happy Creek	Long Branch	Manas-sas Run	Stephens Run	West Run	Willow Brook
Nonpoint source loadings from forest	<1%	1%	1%	<1%	1%	<1%	<1%	<1%
Nonpoint source loadings from cropland	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%
Nonpoint source loadings from pasture	37%	41%	14%	64%	11%	44%	42%	37%
Nonpoint source loadings from hayland	2%	1%	<1%	1%	<1%	2%	<1%	2%
Nonpoint source loadings from developed	1%	7%	14%	<1%	6%	11%	3%	2%
Nonpoint source loadings from transportation	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%
Direct nonpoint source loadings to the stream from livestock	44%	28%	17%	23%	42%	16%	36%	41%
Direct nonpoint source loadings to the stream from wildlife	15%	15%	26%	9%	34%	19%	13%	17%
Interflow and groundwater contribution	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%
Straight-pipe discharges to stream	<1%	2%	1%	<1%	4%	5%	2%	<1%
Permitted point source loadings (including SSOs)	<1%	4%	27%	<1%	<1%	<1%	1%	<1%

8.1.4. **Future Conditions**

The Warren, Frederick, and Clarke County Comprehensive Plans adopted in 2013 (date not available), June 23, 2003 July 14, 2011, and March 18, 2014, respectively, outline potential growth in the study watersheds. In the Clarke County portion of the sturdy watersheds, this potential growth was minimal so no increase in population and households was implemented. The Warren County Comprehensive Plan indicted anticipated population growth in the next 15 years to be about 24%, with most of this growth directed toward areas with municipal water and sewer infrastructure. Similarly, the Frederick County Comprehensive Plan indicated an anticipated growth of about 35% over the same period, with most of this growth directed toward areas with municipal water and sewer infrastructure. Adjustments were made to the model to reflect these future growth trends in populations, households, and pets. As a conservative measure, no adjustments were made to land use composition in the study watersheds.

8.1.5. **Allocation Scenarios**

A variety of allocation scenarios were evaluated to meet the *E. coli* TMDL goal of a calendar-month geometric mean concentration less than 126 cfu/100 mL. The scenarios and results are summarized in Table 8.2 – Table 8.9 for Borden Marsh Run, Crooked Run, Happy Creek, Long Branch, Manassas Run, Stephens Run, West Run, and Willow Brook, respectively. Recall that these reductions are those used for modeling, and implementation of these reductions will require implementation of BMPs as discussed at the beginning of this chapter. The recommended scenarios are highlighted in yellow in Table 8.2 – Table 8.9.

Scenarios labeled “1” are shown in Table 8.2 – Table 8.9 to illustrate that there is a need for reductions in directly deposited wildlife loads in the Happy Creek and Manassas Run watersheds to meet the water quality standard. Such wildlife direct deposit load reductions are not required for the Borden Marsh Run, Crooked Run, Long Branch, Stephens Run, West Run, and Willow Brook watersheds. Successful scenarios labeled “2” show the minimum modeled reductions needed to attain compliance with the *E. coli* standard. However, the true measure of water quality improvement in this watershed will not be based on modeled results, but rather on the results of in-stream monitoring. In no scenario presented was a reduction placed on the Forest land use.

Table 8.2. Bacteria allocation scenarios for the Borden Marsh Run watershed.

Scenario No.	Required *E. coli* Loading Reductions to Meet the *E. coli* Standards, %								% Violation of *E. coli* Standard	
	Livestock Direct Dep.	Loads from Pasture	Loads from Cropland	Loads from Hayland	Straight Pipes and Failing Septic Systems	Loads from Developed Areas[a]	Loads from Transportation	Wildlife Direct Deposit	Geo. Mean	Single Sample Max.[b]
	Unsuccessful Scenarios									
Baseline Cond.	0	0	0	0	0	0	0	0	58	39
Successful Scenario										
1	100	100	100	100	100	100	100	0	0	0
2	99	63	45	0	100	70	0	0	0	8

[a] Does not include loads from failing septic systems
[b] The Single Sample Maximum criterion allows up to 10% violation rate.

Table 8.3. Bacteria allocation scenarios for the Crooked Run watershed.

Scenario No.	Required *E. coli* Loading Reductions to Meet the *E. coli* Standards, %								% Violation of *E. coli* Standard	
	Livestock Direct Dep.	Loads from Pasture	Loads from Cropland	Loads from Hayland	Straight Pipes and Failing Septic Systems	Loads from Developed Areas[a]	Loads from Transportation	Wildlife Direct Deposit	Geo. Mean	Single Sample Max.[b]
Unsuccessful Scenarios										
Baseline Cond.	0	0	0	0	0	0	0	0	27	18
Successful Scenario										
1	100	100	100	100	100	100	100	0	0	0
2	74	45	15	0	100	10	0	0	0	9

[a] Does not include loads from failing septic systems
[b] The Single Sample Maximum criterion allows up to 10% violation rate.

Table 8.4. Bacteria allocation scenarios for the Happy Creek watershed.

Scenario No.	Required *E. coli* Loading Reductions to Meet the *E. coli* Standards, %								% Violation of *E. coli* Standard	
	Livestock Direct Dep.	Loads from Pasture	Loads from Cropland	Loads from Hayland	Straight Pipes and Failing Septic Systems	Loads from Developed Areas[a]	Loads from Transportation	Wildlife Direct Deposit	Geo. Mean	Single Sample Max.[b]
Unsuccessful Scenarios										
Baseline Cond.	0	0	0	0	0	0	0	0	32	16
1	100	100	100	100	100	100	100	0	8	1
Successful Scenario										
2	85	55	10	0	100	85	0	25	0	2

[a] Does not include loads from failing septic systems
[b] The Single Sample Maximum criterion allows up to 10% violation rate.

Table 8.5. Bacteria allocation scenarios for the Long Branch watershed.

Scenario No.	Required *E. coli* Loading Reductions to Meet the *E. coli* Standards, %								% Violation of *E. coli* Standard	
	Livestock Direct Dep.	Loads from Pasture	Loads from Cropland	Loads from Hayland	Straight Pipes and Failing Septic Systems	Loads from Developed Areas[a]	Loads from Transportation	Wildlife Direct Deposit	Geo. Mean	Single Sample Max.[b]
Unsuccessful Scenarios										
Baseline Cond.	0	0	0	0	0	0	0	0	52	29
Successful Scenario										
1	100	100	100	100	100	100	100	0	0	0
2	89	80	15	0	100	0	0	0	0	9

[a] Does not include loads from failing septic systems
[b] The Single Sample Maximum criterion allows up to 10% violation rate.

Table 8.6. Bacteria allocation scenarios for the Manassas Run watershed.

Scenario No.	Required *E. coli* Loading Reductions to Meet the *E. coli* Standards, %								% Violation of *E. coli* Standard	
	Livestock Direct Dep.	Loads from Pasture	Loads from Cropland	Loads from Hayland	Straight Pipes and Failing Septic Systems	Loads from Developed Areas[a]	Loads from Transportation	Wildlife Direct Deposit	Geo. Mean	Single Sample Max.[b]
Unsuccessful Scenarios										
Baseline Cond.	0	0	0	0	0	0	0	0	37	20
1	100	100	100	100	100	100	100	0	10	0
Successful Scenario										
2	96	50	10	0	100	0	0	27	0	2

[a] Does not include loads from failing septic systems
[b] The Single Sample Maximum criterion allows up to 10% violation rate.

Table 8.7. Bacteria allocation scenarios for the Stephens Run watershed.

Scenario No.	Required *E. coli* Loading Reductions to Meet the *E. coli* Standards, %								% Violation of *E. coli* Standard	
	Livestock Direct Dep.	Loads from Pasture	Loads from Cropland	Loads from Hayland	Straight Pipes and Failing Septic Systems	Loads from Developed Areas[a]	Loads from Transportation	Wildlife Direct Deposit	Geo. Mean	Single Sample Max.[b]
Unsuccessful Scenarios										
Baseline Cond.	0	0	0	0	0	0	0	0	8	13
Successful Scenario										
1	100	100	100	100	100	100	100	0	0	0
2	44	42	15	0	100	10	0	0	0	9

[a] Does not include loads from failing septic systems
[b] The Single Sample Maximum criterion allows up to 10% violation rate.

Table 8.8. Bacteria allocation scenarios for the West Run watershed.

Scenario No.	Required *E. coli* Loading Reductions to Meet the *E. coli* Standards, %								% Violation of *E. coli* Standard	
	Livestock Direct Dep.	Loads from Pasture	Loads from Cropland	Loads from Hayland	Straight Pipes and Failing Septic Systems	Loads from Developed Areas[a]	Loads from Transportation	Wildlife Direct Deposit	Geo. Mean	Single Sample Max.[b]
Unsuccessful Scenarios										
Baseline Cond.	0	0	0	0	0	0	0	0	40	24
Successful Scenario										
1	100	100	100	100	100	100	100	0	0	0
2	85	50	15	0	100	0	0	0	0	9

[a] Does not include loads from failing septic systems
[b] The Single Sample Maximum criterion allows up to 10% violation rate.

Table 8.9. Bacteria allocation scenarios for the Willow Brook watershed.

Scenario No.	Required *E. coli* Loading Reductions to Meet the *E. coli* Standards, %								% Violation of *E. coli* Standard	
	Livestock Direct Dep.	Loads from Pasture	Loads from Cropland	Loads from Hayland	Straight Pipes and Failing Septic Systems	Loads from Developed Areas[a]	Loads from Transportation	Wildlife Direct Deposit	Geo. Mean	Single Sample Max.[b]
Unsuccessful Scenarios										
Baseline Cond.	0	0	0	0	0	0	0	0	45	25
Successful Scenario										
1	100	100	100	100	100	100	100	0	0	0
2	95	45	15	0	100	0	0	0	0	9

[a] Does not include loads from failing septic systems
[b] The Single Sample Maximum criterion allows up to 10% violation rate.

As a general rule, direct deposit sources (livestock, wildlife, and straight pipes) control violations of the calendar-month geometric mean standard. These sources control the constant inputs to the water body, and thus control the geometric mean of the daily average predictions over the entire month.

Loadings for the existing conditions and the chosen successful TMDL allocation scenario (2) are presented for nonpoint sources by land use in Table 8.10 – Table 8.17 and for direct nonpoint sources in Table 8.18 – Table 8.25.

The fecal coliform allocation scenario loads presented in Table 8.10 – Table 8.25 are the fecal coliform loads that result in in-stream *E. coli* concentrations that meet the applicable *E. coli* water quality standards after application of the VADEQ fecal coliform to *E. coli* translator to the HSPF-predicted mean daily fecal coliform concentrations.

Table 8.10. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Borden Marsh Run.

	Existing Conditions		Allocation Scenario	
Land use category	**Existing Conditions Load ($x10^{12}$ cfu/yr)**	**Percent of total land deposited load from nonpoint sources**	**TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)**	**Percent Reduction from Existing Load**
Cropland	18	1	10	45
Pasture	3,171	97	1,173	63
Hayland	12	<1	12	0
Developed	42	1	12	70
Transportation	1	<1	1	0
Forest	13	<1	13	0
Total	3,257		1,221	63

Table 8.11. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Crooked Run.

	Existing Conditions		Allocation Scenario	
Land use category	**Existing Conditions Load ($x10^{12}$ cfu/yr)**	**Percent of total land deposited load from nonpoint sources**	**TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)**	**Percent Reduction from Existing Load**
Cropland	64	1	55	15
Pasture	4,433	89	2,438	45
Hayland	47	1	47	0
Developed	363	7	327	10
Transportation	1	<1	1	0
Forest	89	2	89	0
Total	4,997		2,957	41

Table 8.12. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Happy Creek.

Land use category	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Cropland	6	<1	5	10
Pasture	1,587	61	714	55
Hayland	3	<1	3	0
Developed	890	34	133	85
Transportation	1	<1	1	0
Forest	116	4	116	0
Total	2,603		972	63

Table 8.13. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Long Branch.

Land use category	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Cropland	114	1	97	15
Pasture	9,574	99	1,915	80
Hayland	7	<1	7	0
Developed	16	<1	16	0
Transportation	0	0	0	0
Forest	7	<1	7	0
Total	9,718		2,042	79

Table 8.14. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Manassas Run.

Land use category	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Cropland	4	<1	4	10
Pasture	1,179	76	589	50
Hayland	2	<1	2	0
Developed	284	18	284	0
Transportation	1	<1	1	0
Forest	84	5	84	0
Total	1,554		964	38

Table 8.15. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Stephens Run.

Land use category	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Cropland	28	1	23	15
Pasture	2,219	86	1,287	42
Hayland	88	3	88	0
Developed	236	9	213	10
Transportation	1	<1	1	0
Forest	25	1	25	0
Total	2,597		1,637	37

Table 8.16. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for West Run.

Land use category	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Cropland	21	<1	18	15
Pasture	4,277	94	2,138	50
Hayland	19	<1	19	0
Developed	142	3	142	0
Transportation	1	<1	1	0
Forest	84	2	84	0
Total	4,544		2,402	47

Table 8.17. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Willow Brook.

Land use category	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Cropland	10	<1	9	15
Pasture	2,696	97	1,483	45
Hayland	8	<1	8	0
Developed	44	2	44	0
Transportation	0	0	0	0
Forest	12	<1	12	0
Total	2,770		1,556	44

Table 8.18. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Borden Marsh Run.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	11.6	77	0.1	99
Wildlife in Streams	3.4	23	3.4	0
Straight Pipes	0	0	0	100
Total	15.0		3.5	77

Table 8.19. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Crooked Run.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	3.6	59	0.9	74
Wildlife in Streams	2.4	40	2.4	0
Straight Pipes	0.1	1	0	100
Total	6.1		3.3	45

Table 8.20. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Happy Creek.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	4.2	37	0.6	85
Wildlife in Streams	6.7	60	5.0	25
Straight Pipes	0.3	3	0	100
Total	11.2		5.7	49

Table 8.21. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Long Branch.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	3.6	74	0.4	89
Wildlife in Streams	1.3	26	1.3	0
Straight Pipes	0	0	0	100
Total	4.9		1.7	66

Table 8.22. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Manassas Run.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	4.3	51	0.2	96
Wildlife in Streams	3.9	45	2.8	27
Straight Pipes	0.4	4	0	100
Total	8.6		3.0	65

Table 8.23. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Stephens Run.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	1.2	44	0.7	44
Wildlife in Streams	1.3	46	1.3	0
Straight Pipes	0.3	10	0	100
Total	2.8		2.0	29

Table 8.24. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for West Run.

	Existing Conditions		Allocation Scenario	
Source	**Existing Conditions Load ($x10^{12}$ cfu/yr)**	**Percent of total direct deposited load from direct nonpoint source**	**TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)**	**Percent Reduction from Existing Load**
Livestock in Streams	7.4	74	1.1	85
Wildlife in Streams	2.3	23	2.3	0
Straight Pipes	0.3	3	0.0	100
Total	18.5		3.4	66

Table 8.25. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Willow Brook.

	Existing Conditions		Allocation Scenario	
Source	**Existing Conditions Load ($x10^{12}$ cfu/yr)**	**Percent of total direct deposited load from direct nonpoint source**	**TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)**	**Percent Reduction from Existing Load**
Livestock in Streams	5.8	73	0.3	95
Wildlife in Streams	2.1	27	2.1	0
Straight Pipes	0	0	0	100
Total	7.9		2.4	70

8.1.6. **Waste Load Allocation**

A Total Waste Load Allocation (WLA_{Total}) was developed for each impaired segment. The WLA_{Total} is the sum of the WLA for each permitted point source facility, a WLA for any applicable MS4 permits in the watershed, and a WLA to account for future growth.

One hundred eleven point source facilities are located in the Shenandoah River tributaries watersheds (Table 4.2). One hundred one of these are general permit coverage for a single family home, and the load from these source were considered small (<10%) relative to the load allocation. A WLA was assigned to the permitted point source facilities in the Crooked Run, Manassas Run, and West Run watersheds. There are no permitted point source facilities in the Borden Marsh Run, Happy Creek, Long Branch, Stephens Run, and Willow Brook watersheds.

The existing sources WLA in each watershed represented ≤ 10% of the TMDL. Therefore, a scenario to account for future growth was set at 2% of the TMDL for permitted operations in each of the study watersheds. This future growth allocation may be allocated to new or expanding dischargers as determined by the VADEQ Virginia Pollutant Discharge Elimination System program. Any permit issued for bacteria control will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

Inclusion of the future growth WLA results in no violations of geometric mean standard. Therefore, it is assumed that future growth in point source dischargers with a consistent permitted bacteria concentration of 126 cfu/100 mL *E. coli* will not cause additional violations of the water quality standards. The calculation of WLA_{Total} for each impairment is presented in Table 8.26 through Table 8.33.

Table 8.26. Estimated annual WLA for *E. coli* loadings (cfu/yr) at the watershed outlet used for the Borden Marsh Run bacteria TMDL.

Permit Number	WLA
1 domestic Sewage General Permits	1.74×10^{9}
Future Growth	2.79×10^{11}
WLA_{Total}	2.81×10^{11}

Table 8.27. Estimated annual WLA for *E. coli* loadings (cfu/yr) at the watershed outlet used for the Crooked Run bacteria TMDL.

Permit Number	WLA
VA0061964	2.61×10^{11}
VA0088811	6.97×10^{10}
VA0023370	6.45×10^{10}
VA0080080	4.35×10^{11}
VAR040115 – VDOT MS4*	1.16×10^{10}
30 domestic Sewage General Permit	5.23×10^{10}
Future Growth	1.32×10^{12}
WLA_{Total}	2.21×10^{12}

*MS4 WLA includes load in Stephens Run watershed, a tributary to Crooked Run.

Table 8.28. Estimated annual WLA for *E. coli* loadings (cfu/yr) at the watershed outlet used for the Happy Creek bacteria TMDL.

Permit Number	WLA
Future Growth	4.27×10^{11}
WLA_{Total}	4.27×10^{11}

Table 8.29. Estimated annual WLA for *E. coli* loadings (cfu/yr) at the watershed outlet used for the Long Branch bacteria TMDL.

Permit Number	WLA
Future Growth	*1.73×10^{11}*
WLA_{Total}	*1.73×10^{11}*

Table 8.30. Estimated annual WLA for *E. coli* loadings (cfu/yr) at the watershed outlet used for the Manassas Run bacteria TMDL.

Permit Number	WLA
VA0059170	*1.22×10^{10}*
VA0089958	*9.58×10^{19}*
7 domestic Sewage General Permit	*1.22×10^{10}*
Future Growth	*2.90×10^{11}*
WLA_{Total}	*3.24×10^{11}*

Table 8.31. Estimated annual WLA for *E. coli* loadings (cfu/yr) at the watershed outlet used for the Stephens Run bacteria TMDL.

Permit Number	WLA
13 domestic Sewage General Permit	*2.26×10^{9}*
Future Growth	*2.84×10^{11}*
WLA_{Total}	*3.07×10^{11}*

Table 8.32. Estimated annual WLA for *E. coli* loadings (cfu/yr) at the watershed outlet used for the West Run bacteria TMDL.

Permit Number	WLA
VA0090247	*3.48×10^{10}*
49 domestic Sewage General Permit	*8.54×10^{10}*
Future Growth	*4.60×10^{11}*
WLA_{Total}	*5.80×10^{11}*

Table 8.33. Estimated annual WLA for *E. coli* loadings (cfu/yr) at the watershed outlet used for the Willow Brook bacteria TMDL.

Permit Number	WLA
1 domestic Sewage General Permit	*1.74×10^{9}*
Future Growth	*2.31×10^{11}*
WLA_{Total}	*2.33×10^{11}*

8.1.7. **Summary of the TMDL Allocation Scenarios for Bacteria**

TMDLs for *E. coli* have been developed for Borden Marsh Run, Crooked Run, Happy Creek, Long Branch, Manassas Run, Stephens Run, West Run, and Willow Brook. The TMDLs address the following issues:

1. The TMDLs meet the calendar-month geometric mean water quality standard.

2. Because *E. coli* loading data were not available to quantify nonpoint source bacterial loads, available fecal coliform loading data were used as input to the HSPF model. This input of fecal coliform loads from indirect sources (land applied) and direct in-stream sources are listed in Table 8.10 – Table 8.25. HSPF uses processes to model land surface build-up, wash-off, and instream die-off to simulate in-stream fecal coliform concentrations. The VADEQ fecal coliform to *E. coli* concentration translator equation was then used to convert the simulated fecal coliform concentrations to *E. coli* concentrations.
3. The TMDLs were developed taking into account all fecal bacteria sources (anthropogenic and natural) from both point and nonpoint sources.
4. An implicit margin of safety (MOS) was incorporated by utilizing professional judgment and conservative estimates of model parameters.
5. Both high- and low-flow stream conditions were considered while developing the TMDLs. In the Shenandoah River tributaries study area, violations of the water quality standard were caused during both low stream flow and high stream flow; because the TMDL was developed using a continuous simulation model, it applies to both high- and low-flow conditions.
6. Both the flow regime and bacteria loading to the streams are seasonal. The TMDLs account for these seasonal effects.

Using equation 8.1, the summary of the bacteria TMDLs for Borden Marsh Run, Crooked Run, Happy Creek, Long Branch, Manassas Run, Stephens Run, West Run, and Willow Brook for the selected allocation scenarios are given in Table 8.34. The LAs in the TMDL equations are the corresponding in-stream annual *E. coli* loads resulting from the allocated nonpoint source fecal coliform loads listed in Table 8.10– Table 8.25.

Table 8.34. Maximum annual *E. coli* loadings (cfu/yr) at the impaired watershed outlets in the Shenandoah River tributaries watersheds.

Impairment	WLA_{total}	LA*	MOS**	TMDL
Borden Marsh Run	2.81×10^{11}	1.37×10^{13}	--	1.40×10^{13}
Crooked Run	2.22×10^{12}	6.39×10^{13}	--	6.61×10^{13}
Happy Creek	4.27×10^{11}	2.09×10^{13}	--	2.13×10^{13}
Long Branch	1.73×10^{11}	8.48×10^{12}	--	8.66×10^{12}
Manassas Run	3.24×10^{11}	1.42×10^{12}	--	1.45×10^{13}
Stephens Run	3.07×10^{11}	1.39×10^{13}	--	1.42×10^{13}
West Run	5.80×10^{11}	2.24×10^{13}	--	2.30×10^{13}
Willow Brook	2.33×10^{11}	1.13×10^{13}	--	1.16×10^{13}

*The LA is the remaining loading allowed after the MOS and WLA are subtracted from the TMDL as determined for the downstream end of the impaired segment, the watershed outlet. This value is different from the tables providing nonpoint source load (Tables 8.8 – 8.19) because of factors such as bacteria die off that occur between the point of deposition and the modeled watershed outlet.

**Implicit MOS

Daily *E. coli* TMDL

The USEPA has mandated that TMDL studies completed in 2007 and later include a daily maximum load as well as the average annual load shown in the previous section. The daily load was determined as the product of a representative flow rate from the watershed and the appropriate concentration criterion from the water quality standard. This section summarizes the daily maximum loads for Borden Marsh Run, Crooked Run, Happy Creek, Long Branch, Manassas Run, Stephens Run, West Run, and Willow Brook.

Hydrologic Considerations

According to guidance from EPA (USEPA, 2006) it is necessary to assess the flow duration curve to determine an appropriate flow rate to use in the load calculation. EPA guidance suggests that the flow duration curve should be plotted using observed continuous flow data. Flow data from the USGS gage used in the hydrologic calibration were used to calculate the daily load. As is specified in the EPA guidance, the observed flows from the Shenandoah River were multiplied by the ratio of each impaired segment's watershed area to the drainage area above the USGS gage. The flow rate corresponding to the 99th percentile flow (that is, the flow rate exceeded by only 1% of the observed flows) was identified for Spout Run at the USGS gage 01636316 as 103 cfs.

Daily Load

Setting a *maximum daily* load will help ensure that the annual loads given in Table 8.35 are appropriately distributed such that on any given day the single sample component of the bacteria water quality standard will be met. The loadings in the annual load tables, being of a long-term nature, will more directly assure compliance with the geometric mean component of the standard. Thus, the maximum daily load was computed as the product of the critical flow condition and the geometric mean criterion (126 cfu/100 mL). Since the annual WLA_{total} is already based on a maximum daily permitted flow and a maximum daily permitted concentration the daily WLA_{total} is calculated as the annual WLA_{total} divided by 365; the daily LA is then the TMDL less the WLA_{total}. The resulting daily maximum loadings are shown in Table 8.35. The actual maximum daily load is dependent upon flow conditions, and progress toward water quality improvement will be assessed against the numeric water quality criteria (126 cfu *E. coli*/100 mL for a calendar month geometric mean, and 235 cfu *E. coli*/100 mL for a single sample).

Table 8.35. Maximum daily *E. coli* loadings (cfu/day) at the watershed outlets.

Watershed	WLA_{total} †	LA	MOS*	TMDL
Borden Marsh Run	7.70×10^{8}	1.38×10^{11}	-	1.39×10^{11}
Crooked Run	6.05×10^{9}	6.94×10^{11}	-	7.00×10^{11}
Happy Creek	1.17×10^{9}	3.26×10^{11}	-	3.27×10^{11}
Long Branch	4.74×10^{8}	7.66×10^{10}	-	7.71×10^{10}
Manassas Run	8.88×10^{8}	2.17×10^{11}	-	2.18×10^{11}
Stephens Run	8.41×10^{8}	1.29×10^{11}	-	1.29×10^{11}
West Run	1.59×10^{9}	2.92×10^{11}	-	2.94×10^{11}
Willow Brook	6.38×10^{8}	1.02×10^{11}	-	1.02×10^{11}

†the WLA will be implemented in accordance with permitting regulations
*Implicit MOS

8.2. *Happy Creek Sediment TMDL*

The objective of a TMDL is to allocate allowable loads among different pollutant sources so that appropriate actions can be taken to achieve water quality standards (USEPA, 1999). The stressor analysis in Happy Creek watershed indicated that sediment was the "most probable stressor", and therefore, sediment will serve as the basis for development of this TMDL. The AllForX approach was used to set appropriate sediment TMDL endpoints and to quantify the MOS for each TMDL watershed (see Appendix G for more details).

8.2.1. **TMDL Components**

The sediment TMDL for Happy Creek watershed was also calculated using Equation 8.1.

The sediment TMDL load for each TMDL watershed was calculated as the value of AllForX (3.47), the point where the regression line between AllForX and the VSCI intersected the VSCI impairment threshold (VSCI = 60), times the all-forest sediment load of each TMDL watershed. Details of the derivation of AllForX for the TMDL and comparison watersheds are provided in Appendix G.

The WLA is comprised of sediment loads from one individual industrial stormwater permitted source, as well as aggregated loads from construction runoff. In addition, a Future Growth WLA was calculated as 1% of the TMDL.

An explicit MOS for each TMDL watershed was also calculated using the AllForX method. The 80% confidence interval was developed around the chosen value of AllForX, based on the number of watersheds included in the regression and the standard deviation of their AllForX values. The MOS was set equal to the difference between the value of AllForX at VSCI = 60 and the value of AllForX at the lower confidence interval limit, multiplied times the all-forest sediment load for each watershed, amounting to 7.7% of the TMDL.

The LA was calculated as the TMDL minus the sum of WLA and MOS. The TMDL load and its components for each TMDL watershed are shown in Table 8.36.

Table 8.36. Happy Creek Sediment TMDL

Impairment	TMDL	WLA		LA	MOS
	Sediment Load (tons/yr)				
Cause Group Code B41R-03-BEN					
Happy Creek	2,511.3	29.05		2,289.8	192.4
VAC-B41R_HPY01A00		VAR050852 Zuckerman Metals, Inc.	2.52 tons/yr		
VAC-B41R_HPY02A00		construction aggregate WLA	1.42 tons/yr		
		Future Growth WLA	25.11 tons/yr		

8.2.2. **Maximum Daily Loads**

The USEPA (2006a) has mandated that TMDL studies submitted since 2007 include a maximum “daily” load (MDL), in addition to the average annual loads shown in Section 8.2. The approach used to develop these MDLs was provided in Appendix B of a related USEPA guidance document (USEPA, 2006b). This appendix entitled “Approaches for developing a Daily Load Expression for TMDLs computed for Longer Term Averages” is dated December 15, 2006. This guidance provides a procedure for calculating an MDL (tons/day) for each watershed and pollutant from the long-term average (LTA) annual TMDL load (tons/yr) and a coefficient of variation (CV) based on annual loads over a period of time. The “LTA to MDL multiplier” for Happy Creek was calculated from the 1997-2013 simulated output of annual sediment loads using the calibrated GWLF model.

Annual simulated sediment loads for Happy Creek ranged from 522 to 6,641 tons/yr, producing a coefficient of variation (CV) = 0.5849. The “LTA to MDL” multiplier was then interpolated from the USEPA guidance and calculated as 3.896. The MDL was calculated as the TMDL divided by 365 days/yr and multiplied by 3.896.

Since the WLA represents permitted loads, no multiplier was applied to these loads. Therefore the daily WLA and components were converted to daily loads by dividing by 365 days/yr. The daily LA was calculated as the MDL minus the daily WLA minus the daily MOS. The resulting sediment MDL and associated components for the Happy Creek watershed are shown in Table 8.37 in units of tons/day.

Expressing the TMDL as a daily load does not interfere with a permit writer's authority under the regulations to translate that daily load into the appropriate permit limitation, which in turn could be expressed as an hourly, weekly, monthly or other measure (USEPA, 2006a).

Table 8.37. Happy Creek Watershed Maximum "Daily" Sediment Load

Impairment	MDL	WLA	LA	MOS
	Sediment Load (tons/day)			
Cause Group Code B41R-03-BEN				
Happy Creek	26.80	0.080	24.67	2.05
VAC-B41R_HPY01A00		VAR050852 Zuckerman Metals, Inc. 0.007 tons/day		
VAC-B41R_HPY02A00		construction aggregate WLA 0.004 tons/day		
		Future Growth WLA 0.069 tons/day		

8.2.3. **Sediment Allocation Scenarios**

The target allocation sediment load for each watershed allocation scenario is the TMDL minus the MOS. Allocation scenarios were created by applying percent reductions to the various land use/source categories until the target allocation load was achieved for Happy Creek watershed.

Two allocation scenarios were created with each requiring a set reduction from "harvested forest" in compliance with regulated management and from the "barren" land use in compliance with the regulated Erosion and Sediment (E&S) programs. Existing regulations on these two land uses are assumed to already reduce sediment by 50% of their rated efficiencies. Scenario 1 applies equal percent reductions from all other land uses and sources, except point sources. Scenario 2 applies equal percent reductions to the two largest sources, and includes reductions from the harvested forest and transitional (barren) land uses. The preferred scenario will be determined by the local Technical Advisory Committee. Future sediment loads along with two allocation scenarios are presented by grouped land uses and sources for the Happy Creek in Table 8.38.

Table 8.38. Sediment TMDL Load Allocation Scenario, Happy Creek

Land Use/ Source Group	Existing Sediment Load (tons/yr)	Future Sediment Load (tons/yr)	Scenario 1		Scenario 2	
			% Reduction	Allocated Load	% Reduction	Allocated Load
Row Crops	211.5	208.6	37.2%	131.1		208.6
Pasture	909.3	883.6	37.2%	555.3	60.4%	349.7
Hay	735.1	714.4	37.2%	449.0		714.4
Forest	559.8	555.3		555.3		555.3
Harvested Forest	43.0	42.6	42.9%	24.4	42.9%	24.4
Developed	668.4	670.1	37.2%	421.1	60.4%	265.2
Transitional	143.8	162.7	25.0%	122.0	25.0%	122.0
Channel Erosion	47.6	50.2	37.2%	31.6		50.2
Permitted WLA	3.9	29.1		29.1		29.1
Total Load	**3,322.3**	**3,316.6**		**2,318.8**		**2,318.8**

Target Allocation Load =	**2,318.8**
% Reduction Needed =	30.1%

Chapter 9: TMDL Implementation and Reasonable Assurance

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the bacteria impairments in the eight tributaries to the Shenandoah River and the benthic impairment on Happy Creek. The second step is to develop a TMDL Implementation Plan. The final step is to implement the TMDL Implementation Plan and to monitor stream water quality to determine if water quality standards are being attained.

Once a TMDL has been approved by USEPA and then the State Water Control Board (SWCB), measures must be taken to reduce pollutant levels in the stream. These measures, which can include the use of better treatment technology and the installation of BMPs, are implemented in an iterative process that is described along with specific BMPs in the Implementation Plan. The process for developing an Implementation Plan has been described in the "TMDL Implementation Plan Guidance Manual", published in July 2003 and available upon request from the DEQ and DCR TMDL project staff or at http://www.deq.virginia.gov/Portals/0/DEQ/Water/TMDL/ImplementationPlans/ipguide.pdf. With successful completion of Implementation Plans, Virginia begins the process of restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved Implementation Plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

Watershed stakeholders will have opportunity to participate in the development of the TMDL Implementation Plan, which is the next step in the TMDL process. Specific goals for BMP implementation will be established as part of the Implementation Plan development. DCR and DEQ will work closely with watershed stakeholders, interested state agencies, and support groups to develop an acceptable Implementation Plan that will result in meeting the water quality target. Stream delisting of Happy Creek impaired stream segments will be based on biological health (i.e. the recovery of benthic macro-invertebrate communities) and not on numerical sediment load reductions.

9.1. *Staged Implementation*

In general, Virginia intends for the required bacteria reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, in agricultural areas of the watershed, the most promising best management practice is livestock exclusion from streams. This has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the cattle deposits themselves and by providing additional riparian buffers.

Additionally, in both urban and rural areas, reducing the human bacteria loading from straight pipe discharges and failing septic systems should be a primary implementation focus because of their health implications, and because they fall under existing regulations. These components could be implemented through education on septic tank pump-outs, a septic system installation/repair/replacement program, and the use of alternative waste treatment systems.

In urban areas, reducing the human bacteria loading from leaking sewer lines and sewage spillage could be accomplished through a sanitary sewer inspection and management program. Other BMPs that might be appropriate for controlling urban wash-off from parking lots and roads and that could be readily implemented may include more restrictive ordinances to reduce fecal loads from pets, improved garbage collection and control, and improved street cleaning.

The iterative implementation of BMPs in the watershed has several benefits:

1. It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;
3. It provides a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;
4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

Watershed stakeholders will have opportunity to participate in the development of the TMDL implementation plan. While specific goals for BMP implementation will be established as part of the implementation plan development, the following Stage 1 scenarios are targeted at controllable, anthropogenic bacteria sources and can serve as starting points for targeting BMP implementation activities.

9.2. *Stage 1 Scenarios*

The goal of the Stage 1 scenarios is to reduce the bacteria loadings from controllable sources (excluding wildlife) such that violations of the single-sample maximum criterion (235 cfu/100mL) are less than 10.5 percent while requiring no reductions from wildlife sources. The Stage 1 scenarios were generated with the same model setup as was used for the TMDL allocation scenarios. One successful scenario was selected for each of the impaired watersheds (Table 9.1).

9.3. *Link to Ongoing Restoration Efforts*

Implementation of these TMDLs will contribute to on-going water quality improvement efforts in Shenandoah River tributaries and efforts aimed at restoring water quality. Implementation of BMPs to address the sediment impairment in Happy Creek will be coordinated with BMPs required to meet bacteria water quality standards.

Table 9.1. Allocation scenario for Stage 1 TMDL implementation for the Shenandoah River tributaries watersheds.

Impaired Segment.	Required Fecal Coliform Loading Reductions to Meet the Stage 1 Goal, %								% Violation of *E. coli* Standard	
	Lives-tock Direct Dep.	Loads from Pastur e	Loads from Crop-land	Loads from Hay-land	Straight Pipes and Failing Septic Systems	Loads from Devel-oped Areas[a]	Loads from Trans-porta-tion	Wildlife Direct Deposit	Geo. Mean	Single Sample Max.[b]
Borden Marsh Run	87	50	15	0	100	15	0	0	10	10
Crooked Run	45	40	10	0	100	5	0	0	3	10
Happy Creek	38	15	5	0	100	15	0	0	27	9
Long Branch	80	77	10	0	100	0	0	0	5	10
Manassa s Run	44	30	5	0	100	0	0	0	28	9
Stephens Run	20	34	10	0	100	5	0	0	3	10
West Run	78	43	10	0	100	0	0	0	3	10
Willow Brook	80	35	10	0	100	0	0	0	10	10

9.4. *Reasonable Assurance for Implementation*

9.4.1. Follow-up Monitoring

Following the development of the TMDLs, the Department of Environmental Quality (DEQ) will make every effort to continue to monitor the impaired streams in accordance with its ambient monitoring program. VADEQ's Ambient Watershed Monitoring Plan for conventional pollutants calls for watershed monitoring to take place on a rotating basis, bi-monthly for two consecutive years of each six-year cycle. In accordance with VADEQ Guidance Memo No. 03-2004, during periods of reduced resources, monitoring can temporarily discontinue until the TMDL staff determines that implementation measures to address the source(s) of impairments are being installed. Monitoring can resume at the start of the following fiscal year, next scheduled monitoring station rotation, or where deemed necessary by the regional office or TMDL staff, as a new special study.

The purpose, location, parameters, frequency, and duration of the monitoring will be determined by the VADEQ staff, the Implementation Plan Steering Committee, and local stakeholders. Whenever possible, the location of the follow-up monitoring station(s) will be the same as the listing station(s). At a minimum, the monitoring station must be representative of the original impaired segment. The details of the follow-up monitoring will be outlined in the Annual Water Monitoring Plan prepared by each VADEQ Regional Office. Other agency personnel, watershed stakeholders, etc. may provide input on the Annual Water Monitoring Plan. These recommendations must be made to the VADEQ regional TMDL coordinator by September 30 of each year.

DEQ will continue to monitor benthic macro-invertebrates and habitat in accordance with its biological monitoring program at stations 1BHPY001.29 and 1BHPY002.67 on Happy Creek. DEQ will continue to use data from this monitoring station to evaluate improvements in the benthic community and the effectiveness of TMDL implementation in attainment of the general water quality standard.

DEQ staff, in cooperation with the Implementation Plan Steering Committee and local stakeholders, will continue to use data from the ambient monitoring stations to evaluate reductions in pollutants ("water quality milestones" as established in the Implementation Plan), the effectiveness of the TMDL in attaining and maintaining water quality standards, and the success of implementation efforts. Recommendations may then be made, when necessary, to target implementation efforts in specific areas and continue or discontinue monitoring at follow-up stations.

In some cases, watersheds will require monitoring above and beyond what is included in VADEQ's standard monitoring plan. Ancillary monitoring by citizens, watershed groups, local government, or universities is an option that may be used in such cases. An effort should be made to ensure that ancillary monitoring follows established QA/QC guidelines in order to maximize compatibility with VADEQ monitoring data. In instances where citizens' monitoring data are not available and additional monitoring is needed to assess the effectiveness of targeting efforts, TMDL staff may request of the monitoring managers in each regional office an increase in the number of stations or monitor existing stations at a higher frequency in the watershed. The additional monitoring beyond the original bimonthly single station monitoring will be contingent on staff resources and available laboratory budget. More information on citizen monitoring in Virginia and QA/QC guidelines is available at http://www.deq.virginia.gov/Programs/Water/WaterQualityInformationTMDLs/WaterQualityMonitoring/CitizenMonitoring.aspx.

To demonstrate that the watershed is meeting water quality standards in watersheds where corrective actions have taken place (whether or not a TMDL or TMDL Implementation Plan has been completed), VADEQ must meet the minimum data requirements from the original listing station or a station representative of the originally listed segment. The minimum data requirement for conventional pollutants (bacteria, dissolved oxygen, etc) is bimonthly monitoring for two consecutive years. For biological monitoring, the minimum requirement is two consecutive samples (one in the spring and one in the fall) in a one year period.

9.4.2. **Regulatory Framework**

While section 303(d) of the Clean Water Act and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. EPA also requires that all new or revised National Pollutant Discharge Elimination System (NPDES) permits must be consistent with the TMDL WLA pursuant to 40 CFR §122.44 (d)(1)(vii)(B). All such permits should be submitted to EPA for review.

Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQMIRA) directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). WQMIRA also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

For the implementation of the WLA component of the TMDL, the Commonwealth intends to utilize the Virginia NPDES (VPDES) program, which typically includes consideration of the WQMIRA requirements during the permitting process. Requirements of the permit process should not be duplicated in the TMDL process, and with the exception of stormwater related permits, permitted sources are not usually addressed during the development of a TMDL implementation plan.

For the implementation of the TMDL's LA component, a TMDL implementation plan addressing at a minimum the WQMIRA requirements will be developed. Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan. Regional and local offices of VADEQ and other cooperating agencies are technical resources to assist in this endeavor.

In response to a Memorandum of Understanding (MOU) between EPA and VADEQ, VADEQ also submitted a draft Continuous Planning Process to EPA in which VADEQ commits to regularly updating the Water Quality Management Plans (WQMPs). Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

VADEQ staff will present both EPA-approved TMDLs and TMDL implementation plans to the State Water Control Board for inclusion in the appropriate WQMP, in accordance with the Clean Water Act's Section 303(e) and Virginia's Public Participation Guidelines for Water Quality Management Planning.

VADEQ staff will also request that the State Water Control Board (SWCB) adopt TMDL WLAs as part of the Water Quality Management Planning Regulation (9VAC 25-720), except in those cases when permit limitations are equivalent to numeric criteria contained in the Virginia Water Quality Standards, such as is the case for bacteria. This regulatory action is in accordance with §2.2-4006A.4.c and §2.2-4006B of the Code of Virginia. SWCB actions relating to water quality management planning are described in the public participation guidelines referenced above and can be found on VADEQ's web site under

http://www.deq.virginia.gov/Programs/Water/WaterQualityInformationTMDLs/TMDL/Regulation.aspx.

9.4.3. **Stormwater Permits**

VADEQ coordinates the State program that regulates the management of pollutants carried by storm water runoff. VADEQ regulates storm water discharges associated with "industrial activities", from construction sites, and from municipal separate storm sewer systems (MS4s).

It is the intent of the Commonwealth that TMDLs implement existing regulations and programs where they apply. The VDOT MS4 permit (Permit VAR040115) area, defined by the 2000 and 2010 Census Urbanized Areas associated with the City of Winchester, includes portions of the Stephens Run and Crooked Run watersheds. A wasteload allocation for this MS4 permit was included in the Total WLA for Crooked Run. More information is available on VADEQ's web site through the following link: http://www.deq.virginia.gov/Programs/Water/StormwaterManagement/VSMPPermits/MS4Permits.aspx. Additional information on Virginia's Stormwater Management program can be found at

http://www.deq.virginia.gov/Programs/Water/StormwaterManagement.aspx.

9.4.4. **Implementation Funding Sources**

Cooperating agencies, organizations and stakeholders must identify potential funding sources available for implementation during the development of the implementation plan in accordance with the "Virginia Guidance Manual for Total Maximum Daily Load Implementation Plans". Potential sources for implementation may include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, EPA Section 319 funds, the Virginia State Revolving Loan Program, Virginia Agricultural Best Management Practices Cost-Share Programs, the Virginia Water Quality Improvement Fund, tax credits and landowner contributions. The TMDL Implementation Plan Guidance Manual contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

9.4.5. **Attainability of Primary Contact Recreation Use**

In some streams for which TMDLs have been developed, water quality modeling indicates that even after removal of all bacteria sources (other than wildlife), the stream will not attain standards under all flow regimes at all times. These streams may not be able to attain standards without some reduction in wildlife load.

With respect to these potential reductions in bacteria loads attributed to wildlife, Virginia and EPA are not proposing the elimination of wildlife to allow for the attainment of water quality standards. However, if bacteria levels remain high and localized overabundant populations of wildlife are identified as the source, then measures to reduce such populations may be an option if undertaken in consultation with the Department of Game and Inland Fisheries (DGIF) or the United States Fish and Wildlife Service (USFWS). Additional information on DGIF's wildlife programs can be found at http://www.dgif.virginia.gov/wildlife/game/. While managing such overpopulations of wildlife remains as an option to local stakeholders, the reduction of wildlife or changing a natural background condition is not the intended goal of a TMDL.

To address the overall issue of attainability of the primary contact criteria, Virginia proposed during its latest triennial water quality standards review a new "secondary contact" category for protecting the recreational use in state waters. On March 25, 2003, the Virginia State Water Control Board adopted criteria for "secondary contact recreation" which means "a water-based form of recreation, the practice of which has a low probability for total body immersion or ingestion of waters (examples include but are not limited to wading, boating and fishing)". These new criteria became effective on February 12, 2004 and can be found at http://www.deq.virginia.gov/Portals/0/DEQ/Water/WaterQualityStandards/WQS_eff_6JAN2011.pdf.

In order for the new criteria to apply to a specific stream segment, the primary contact recreational use must be removed. To remove a designated use, the state must demonstrate 1) that the use is not an existing use, 2) that downstream uses are protected, and 3) that the source of contamination is natural and uncontrollable by effluent limitations and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10). This and other information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted as amendments to the water quality standards regulations. Watershed stakeholders and EPA will be able to provide comment during this process.

The process to address potentially unattainable reductions based on the above is as follows: First is the development of a stage 1 scenario such as those presented previously in this chapter. The pollutant reductions in the stage 1 scenario are targeted primarily at the controllable, anthropogenic bacteria sources identified in the TMDL, setting aside control strategies for wildlife except for cases of nuisance populations. During the implementation of the stage 1 scenario, all controllable sources would be reduced to the maximum extent practicable using the iterative approach described in Section 9.1 above. VADEQ will re-assess water quality in the stream during and subsequent to the implementation of the stage 1 scenario to determine if the water quality standard is attained. This effort will also evaluate if the modeling assumptions were correct. If water quality standards are not being met, and no additional cost-effective and reasonable best management practices can be identified, a UAA may be initiated with the goal of re-designating the stream for secondary contact recreation.

9.4.6. **Reasonable Assurance Summary**

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of DEQ, DCR, and other cooperating agencies.

Once developed, DEQ intends to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e). In response to a Memorandum of Understanding (MOU) between USEPA and DEQ, DEQ also submitted a draft Continuous Planning Process to USEPA in which DEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

Taken together, the follow-up monitoring, WQMIRA, public participation, and the Continuing Planning Process, comprise a reasonable assurance that the Borden Marsh Run, Crooked Run, Happy Creek, Long Branch, Manassas Run, Stephens Run, West Run, and Willow Brook bacteria TMDLs and the Happy Creek sediment TMDL will be implemented and water quality will be improved and the aquatic life use restored.

Chapter 10: Public Participation

Public participation was elicited at every stage of the TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made.

The first Public Meeting for a number of Shenandoah Tributary TMDLs was held at the North Warren Fire House, Celebration Hall in Front Royal, Virginia on January 9, 2014, where the TMDL process was introduced, local stream impairments were presented, and comments were solicited from the stakeholder group. The first public meeting was attended by 34 people.

The first Technical Advisory Committee Meeting was held on, January 29, 2014 at the Northern Shenandoah Valley Regional Commission office in Front Royal, Virginia. The purpose of that meeting was to introduce agency stakeholders to the TMDL process and to discuss the impairments identified on stream segments in these watersheds. The TAC meeting was attended by 22 people.

A second Technical Advisory Committee meeting was held on March 11, 2014, at the Samuels Public Library in Front Royal. The results from the stressor analysis were presented, along with bacteria TMDL source assessment results, and comments were solicited from the stakeholder group. The second TAC meeting was attended by 23 people.

A third Technical Advisory Committee meeting was held on April 17, 2014 at the Long Branch Plantation in Millwood, Virginia to present modeling procedures, draft modeling results, and to solicit feedback on the proposed TMDL strategy. The TAC meeting was attended by 15 people.

A fourth Technical Advisory Committee meeting was held as an online webinar on June 2, 2014 from the DEQ Regional Office in Harrisonburg, Virginia to present the AllForX methodology as applied to Happy Creek for setting a sediment TMDL endpoint, to present initial modelling results, and to discuss methodology for incorporating future growth. The number of stakeholders participating in the call included 3 people at the DEQ office and 8 people calling in online.

A fifth Technical Advisory Committee meeting was held on July 23, 2014 at the Smithsonian Conservation Biology Institute, just outside Front Royal, Virginia, to present final TMDL and allocation scenarios. This final TAC meeting was attended by 21 stakeholders.

A final public meeting was held on _________________ to present the draft TMDL report to address benthic impairments in the Happy Creek watershed in conjunction with the other Shenandoah Tributaries Bacteria TMDLs. This final TMDL public meeting was attended by __ stakeholders. The public comment period ended on ___________.

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Appendix A: Glossary of Terms

Allocation

That portion of a receiving water's loading capacity that is attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources.

Allocation Scenario

A proposed series of point and nonpoint source allocations (loadings from different sources), which are being considered to meet a water quality planning goal.

Background levels

Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering and dissolution.

BASINS (Better Assessment Science Integrating Point and Nonpoint Sources)

A computer-run tool that contains an assessment and planning component that allows users to organize and display geographic information for selected watersheds. It also contains a modeling component to examine impacts of pollutant loadings from point and nonpoint sources and to characterize the overall condition of specific watersheds.

Best Management Practices (BMP)

Methods, measures, or practices that are determined to be reasonable and cost-effective means for a land owner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.

Bacteria Source Tracking

A collection of scientific methods used to track sources of fecal coliform.

Calibration

The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.

Die-off (of fecal coliform)

Reduction in the fecal coliform population due to predation by other bacteria as well as by adverse environmental conditions (e.g., UV radiation, pH).

Direct nonpoint sources

Sources of pollution that are defined statutorily (by law) as nonpoint sources that are represented in the model as point source loadings due to limitations of the model. Examples include: direct deposits of fecal material to streams from livestock and wildlife.

Failing septic system

Septic systems in which drain fields have failed such that effluent (wastewater) that is supposed to percolate into the soil, now rises to the surface and ponds on the surface where it can flow over the soil surface to streams or contribute pollutants to the surface where they can be lost during storm runoff events.

Fecal coliform

A type of bacteria found in the feces of various warm-blooded animals that is used as indicator of the possible presence of pathogenic (disease causing) organisms. *E. coli* bacteria are a subset of this group found to more closely correlate with human health problems.

Geometric mean

The geometric mean is simply the nth root of the product of n values. Using the geometric mean lessens the significance of a few extreme values (extremely high or low values). In practical terms, this means that if you have just a few bad samples, their weight is lessened.

Mathematically the geometric mean, $\bar{x}_g$, is expressed as:

$$\bar{x}_g = \sqrt[n]{x_1 \cdot x_2 \cdot x_3 \ldots \cdot x_n}$$

where n is the number of samples, and x_i is the value of sample i.

HSPF (Hydrological Simulation Program-Fortran)

A computer-based model that calculates runoff, sediment yield, and fate and transport of various pollutants to the stream. The model was developed under the direction of the U.S. Environmental Protection Agency (EPA).

Hydrology

The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

Instantaneous or Single sample maximum criterion

The instantaneous criterion or instantaneous water quality standard is the value of the water quality standard that should not be exceeded at any time. For example, the Virginia instantaneous water quality standard for *E. coli* is 235 cfu/100 mL. If this value is exceeded at any time, the water body is in violation of the state water quality standard.

Load allocation (LA)

The portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background.

Margin of Safety (MOS)

A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody. The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models).

Model

Mathematical representation of hydrologic and water quality processes. Effects of land use, slope, soil characteristics, and management practices are included.

Nonpoint source

Pollution that is not released through pipes but rather originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.

Pathogen

Disease-causing agent, especially microorganisms such as bacteria, protozoa, and viruses.

Point source

Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.

Pollution

Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.

Reach

Segment of a stream or river.

Runoff

That part of rainfall or snowmelt that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.

Septic system

An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives liquid and solid wastes from a residence or business and a drainfield or subsurface absorption system consisting of a series of tile or percolation lines for disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.

Simulation

The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.

Straight pipe

Delivers wastewater directly from a building, e.g., house, milking parlor, to a stream, pond, lake, or river.

Total Maximum Daily Load (TMDL)

The sum of the individual wasteload allocations (WLA's) for point sources, load allocations (LA's) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

Urban Runoff

Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.

Validation (of a model)

Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical process under investigation. This follows the calibration of the model and ensures that the calibrated values adequately represent the watershed.

Wasteload allocation (WLA)

The portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation.

Water quality standard

Law or regulation that consists of the beneficial designated use or uses of a water body, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular water body, and an anti-degradation statement.

Watershed

A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

For more definitions, see the Virginia Cooperative Extension publications available online:

Glossary of Water-Related Terms. Publication 442-758.
http://www.ext.vt.edu/pubs/bse/442-758/442-758.html

and

TMDLs (Total Maximum Daily Loads) - Terms and Definitions. Publication 442-550.
http://www.ext.vt.edu/pubs/bse/442-550/442-550.html

Appendix B: Source Assessment

Humans and Pets

The Shenandoah River tributaries watersheds have an estimated permanent population of 25,250 (9,962 households with an average of 2.21 to 3.1 people per household, depending on county). The number of households and the number of people per household for the watershed was determined from addressable structures data supplied by Clarke County, Frederick County, and Warren County governments and the 2010 Census of Population and Housing for Virginia. The household and population numbers for 2013 were then calculated by projecting linear interpolation from 2000 to 2010. Fecal coliform from humans can be transported to streams from failing septic systems, via straight pipes discharging directly into streams, sewage spills, or through leaky sewer lines. Although leaky sewer lines are not explicitly accounted for in modeling for this TMDL, they are considered to be part of the residential load, and should be addressed where found during implementation. Professional judgment was used to specify 1 unit pet per household, applied to all households for the Shenandoah River tributaries watersheds.

Failing Septic Systems

Septic system failure can result in the rise of effluent to the soil surface. Surface runoff can transport the effluent, containing fecal coliform, to receiving waters. The number of failing septic systems in each sub-watershed was determined by analyzing the ages of the structures in the watershed and applying a failure rate based on the age category. The U.S. Census (2010) provides an estimate of house ages in its summary file 3. An estimate was made for each Census block group of the fraction of houses in old (pre-1970), middle (1970-1989), and new (post-1989) age categories. These numbers were estimated for 2013 by linear interpolation. This fraction was applied to the total number of houses in each block group to obtain an estimate of the number of houses in each age group in each sub-watershed. Forty percent of old houses, 20% of middle-aged houses, and 3% of new houses were assumed to have failing septic systems.

Daily total fecal coliform load to the land from a failing septic system in each sub-watershed was determined by multiplying the average occupancy rate for that sub-watershed (occupancy rate of houses ranged from 2.21 to 3.1 persons per household (Census Bureau, 2010)) by the per capita fecal coliform production rate of 3.6×10^8 cfu/day (Geldreich, 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a sub-watershed with an occupancy rate of 1 person/household is 3.6×10^8 cfu/day. Transport of some portion of the fecal coliform to a stream by runoff may occur. The estimated number of failing septic systems in the watershed is given in Table B.1.

Straight Pipes

Bacteria discharged from straight pipes enter the stream directly, without treatment or die-off. Straight pipe numbers and possible sub-watershed locations were calculated as a 10% fraction of total number of old and middle age, unsewered houses with stream access. Based on this criterion, it was projected that 14 houses with straight pipes exist in the Shenandoah River tributaries watersheds. The number of straight pipes in watersheds is given in Table B.1.

Daily total fecal coliform load to the stream from a straight pipe in each sub-watershed was determined by multiplying the average occupancy rate for that sub-watershed by the per capita fecal coliform production rate of 3.6×10^8 cfu/day (Geldreich, 1978). Hence, the total fecal coliform loading to the stream from a single straight pipe in a sub-watershed with an occupancy rate of 1 person/household is 3.6×10^8 cfu/day.

Table B.1. Estimated Household and Pet Population Breakdown by Sub-watershed for the Shenandoah River tributaries watersheds.

Sub-Watershed	Sewered Houses	Houses with Septic Systems in each age category			Failing Septic Systems	Straight Pipes	Pet Population
		Old	Mid-age	New			
1	0	19	15	14	11	0	96
2	52	84	63	62	48	2	263
3	0	47	50	62	31	0	159
4	1	67	66	50	42	1	185
5	0	26	27	28	17	0	81
6	64	56	56	54	35	0	461
7	0	3	3	5	2	0	11
8	0	23	28	58	17	0	109
9	399	269	286	162	170	3	1,119
10	0	22	18	30	13	0	140
11	264	48	90	171	42	1	1,148
12	0	4	3	7	2	0	28
13	1	16	12	30	10	0	118
14	0	6	6	5	4	0	17
15	3	61	62	46	38	0	172
16	0	5	5	4	3	0	14
17	0	7	6	6	4	0	19
18	0	46	32	53	26	0	131
19	0	19	13	22	11	0	54
20	0	26	12	12	13	0	57
21	0	7	4	8	4	0	19
22	79	1	0	0	0	0	80
23	1,507	24	35	56	18	1	1,623
24	555	1	0	0	0	0	556
25	2,041	6	3	1	3	0	2,051
26	8	8	15	20	7	0	51
27	0	104	185	229	85	1	519
28	0	30	56	81	26	1	176
29	40	49	81	128	40	1	299
30	3	117	279	491	117	2	892
31	1	43	104	176	43	1	325
Total	**5,018**	**1,244**	**1,615**	**2,071**	**882**	**14**	**10,973**

Pets

The Humane Society of the United States conducts biannual pet owner surveys in the United States and reports a summary of these findings. For the 2012-2013 survey: 47% of American households owned an average of 1.47 dogs, and 33% of American households owned an average of 2.11 cats (HSUS, 2013). Assuming that a unit pet is one dog or two cats, this yields (0.47*1.47 + (0.33*2.11)/2) = 1.077 unit pets per household. Stakeholder input indicated that there were larger numbers of pets in select subwatersheds. Therefore, the pet population in the Shenandoah River tributaries watersheds was calculated at a rate varying from 1 to 2.85 pet units per permanent household. Given this assumption, there are an estimated 10,973 pets in the Shenandoah River tributaries watersheds.

A dog produces fecal coliform at a rate of 4.5 x 10^8 cfu/day (Weiskel et al., 1996); this was assumed to be representative of a 'unit pet' – one dog or several cats. The pet population distribution among the sub-watersheds is listed in Table B.1. Pet waste is generated in residential areas; surface runoff can transport bacteria in pet waste from these areas to the stream.

Cattle

Fecal coliform in cattle waste can be directly excreted to the stream, or it can be transported to the stream via surface runoff from animal waste deposited on pastures or applied to crops or pasture.

Distribution of Dairy and Beef Cattle

There are currently two dairy farms in the Shenandoah River tributaries watersheds. The number of dairy farms was acquired by the Virginia Department of Environmental Quality (DEQ).

The population of beef cattle in the Shenandoah River tributaries watersheds was initially estimated from the 2007 Agricultural Census. The total number of beef cows modeled throughout the year varied due to the presence or absences of calves and their weights relative to the adult cattle.

Beef cattle spend varying amounts of time in streams and pastures, depending on the time of year. Accordingly, the proportion of fecal coliform deposited in any given land area varies throughout the year. Stream access for all beef cattle farms was estimated based on watershed visits and pasture proximity to the stream.

Because there are not many dairy operations in this watershed, it is impossible to report the dairy cows on a sub-watershed basis without allowing the reader to tie the numbers to a specific farm. Therefore, to preserve the confidentiality of the dairy farmer personally contacted, the populations for all cattle are reported on the basis of the impaired watersheds. The estimated number of beef and dairy cattle are listed in Table B.2 for the Shenandoah River tributaries watersheds.

Table B.2. Beef and Dairy Cattle Populations in the Shenandoah River tributaries watersheds.

Sub-watershed	Cattle*	Sub-watershed	Cattle*
1	30	17	150
2	207	18	220
3	207	19	130
4	204	20	125
5	164	21	1,370
6	320	22	5
7	11	23	91
8	236	24	2
9	171	25	3
10	292	26	19
11	111	27	93
12	11	28	76
13	74	29	126
14	25	30	33
15	320	31	52
16	138	Total	5,016

* Cow-calf pairs

The following assumptions and procedures were used to estimate the distribution of cattle (and thus, fecal coliform produced by cattle) among different land use types and in streams:

a) Cattle are only confined as detailed in the table below. This table reflects the communications with farmers and agency personnel.
b) All other cattle are on pasture.
c) Cattle with stream access (determined as described earlier) will spend varying amounts of time in the stream during different seasons (Table B.3). Cattle spend more time in the stream during the three summer months to protect their hooves from hornflies, among other reasons.
d) Thirty percent of cattle in and around streams directly deposit fecal coliform into the stream. The remaining 70% of the feces is deposited on pastures.

The resulting numbers of cattle in pastures and streams for all sub-watersheds are given in Table B.4.

Table B.3. Time spent by cattle in confinement and in the stream.

Month	Fraction of time spent in confinement			Time spent in the stream (hours/day)
	Milk Cows (range; typical)	Dry Cows and Heifers (range; typical)	Beef Cattle (range; typical)	
January	25%-100%; 75%	17%-40%; 40%	0%-40%; 20%	0.5
February	25%-100%; 75%	17%-40%; 40%	0%-40%; 20%	0.5
March	25%-100%; 40%	0%-15%; 0%	0%-0.7%; 0%	0.75
April	25%-100%; 30%	0%-15%; 0%	0%-0.7%; 0%	1
May	25%-100%; 30%	0%-15%; 0%	0%-0.7%; 0%	1.5
June	25%-100%; 30%	0%-15%; 0%	0%-0.7%; 0%	3.5
July	25%-100%; 30%	0%-15%; 0%	0%-0.7%; 0%	3.5
August	25%-100%; 30%	0%-15%; 0%	0%-0.7%; 0%	3.5
September	25%-100%; 30%	0%-15%; 0%	0%-0.7%; 0%	1.5
October	25%-100%; 30%	0%-15%; 0%	0%-0.7%; 0%	1
November	25%-100%; 40%	0%-15%; 0%	0%-0.7%; 0%	0.75
December	25%-100%; 75%	17%-40%; 40%	0%-40%; 20%	0.5

Table B.4. Distribution of the cattle population among land use types and stream in the Shenandoah River tributaries watersheds.

Month	Confinement	Pasture	Streams*
January	2,456	3,112	2
February	2,751	3,555	2
March	260	6,190	6
April	195	6,401	9
May	195	6,544	13
June	195	6,673	32
July	195	6,820	33
August	195	6,967	33
September	195	7,134	15
October	195	4,815	6
November	260	4,936	5
December	2,382	3,002	2

*Number of bovine equivalent defecations in the stream

Direct Manure Deposition in Streams

Direct manure loading to streams is due to beef cattle (see above) defecating in the stream. Manure loading increases during the warmer months, when cattle spend more time in water. The potential average annual manure loadings directly deposited by cattle in the stream for the Shenandoah River study area, based on distribution estimates listed in Table B.4, is 2.90 x 10^5 pounds. The associated average daily fecal coliform loading to the streams for Shenandoah River study area is 1.14 x 10^{11} cfu. Part of the fecal coliform deposited in the stream stays suspended, while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that suspended fecal coliform bacteria are the primary form transported with the flow. Sediment-bound fecal coliform bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. Die-off of fecal coliform in the stream depends on sunlight, predation, turbidity, and other environmental factors.

Direct Manure Deposition on Pastures

Cattle that graze on pastures (see above) but do not deposit in streams contribute the majority of fecal coliform loading on pastures. Manure loading on pasture was estimated by multiplying the total number of cattle on pasture by the amount of manure produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Because the confinement schedule of cattle changes with season: loading on pasture also changes with season.

Pasture has an average annual cattle manure loading of 6,260 lb/ac for the Shenandoah River tributaries watersheds. The associated fecal coliform loading from cattle to pasture on a daily basis averaged over the year is 2.45 x 10^{9} cfu/ac/day for the Shenandoah River tributaries watersheds. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

Land Application of Liquid Dairy Manure

A typical milk cow weighs 1,400 lb and produces 17 gal of liquid manure daily (ASAE, 1998). Based on the monthly confinement schedule (above) and the number of lactating cows, annual liquid dairy manure production in the Shenandoah River tributaries watersheds is 1.73 x 10^{6} gal. Based on the per capita fecal coliform production of lactating cows, the fecal coliform concentration in fresh liquid manure is 2.17 x 10^{8} cfu/gal. Liquid dairy manure receives priority over other manure types (poultry litter and solid cattle manure) when applied to land. Based on input from dairy farmers, a liquid dairy manure application rate of 6,600 gal/ac-year to cropland land use category was used. Based on availability of land and liquid dairy manure, as well as the assumptions regarding application rates and priority of application, it was estimated that liquid dairy manure was applied to 262 acres (9.4%) of cropland.

For modeling purposes, a seven-year crop rotation in the watersheds with three years of corn-rye and four years of rotational hay was assumed. It was assumed that 50% of the corn acreage was under no-till cultivation. Liquid manure is applied to cropland during February through May (prior to planting) and in October-November (after the crops are harvested). For spring application to cropland, liquid manure is applied on the soil surface to rotational hay and no-till corn and is incorporated into the soil for corn in conventional tillage. In fall, liquid manure is incorporated into the soil for cropland under rye and surface-applied to cropland under rotational hay. It was assumed that only 10% of the subsurface-applied fecal coliform was available for removal in surface runoff based on local knowledge. The application schedule of liquid manure is given in Table B.5. Dry cows and heifers were assumed to produce only solid manure.

Table B.5. Schedule of cattle manure application on the Shenandoah River tributaries watersheds.

Month	Solid cattle manure applied (%)*	Liquid dairy manure applied (%)*
January	0	0
February	5	5
March	25	25
April	20	20
May	5	5
June	5	10
July	5	0
August	5	5
September	10	15
October	10	5
November	10	10
December	0	0

* As percent of annual production

Land Application of Solid Manure

Solid manure produced by beef cattle during confinement is collected for land application. The application schedule for solid manure is given in B.5 .. The number of cattle, their typical weights, amounts of solid manure produced, and fecal coliform concentration in fresh manure are listed in Table B.6. Solid manure is last on the priority list for application to land (it falls behind liquid manure). The amount of solid manure produced in each sub-watershed was estimated based on the populations of beef cattle in the sub-watershed (Table B.6) and their confinement schedules (Table B.3).

Table B.6. Estimated solid manure production characteristics.

Type of cattle	Population (Shenandoah)	Typical weight (lb)	Solid manure produced (lb/animal-day)	Fecal coliform concentration in fresh manure (x 10^6 cfu/lb)
Dry cow	60	1,400[†]	115[‡]	217[§]
Heifer	612	640[††]	40.7[†]	281[§]
Beef[*]	3,691	1000[†]	60[†]	143[§]

[†]Source: ASAE (1998)
[‡]Source: MWPS (1993)
[§]Based on per capita fecal coliform production per day (Table 4.1) and manure production
[††]Based on weighted average weight assuming that 57% of the animals are older than 10 months (900 lb ea.), 28% are 1.5-10 months (400 lb ea.) and the remainder are less than 1.5 months (110 lb ea.) (MWPS, 1993)

Solid cattle manure is applied at the rate of 12 tons/ac-year to cropland and hay land, with priority given to cropland. Solid manure is applied to cropland from February through May, and October through November. Solid manure can be applied to hay land anytime of the year. Based on availability of land and solid manure, as well as the assumptions regarding application rates and priority of application, it was estimated that solid cattle manure was applied to 431 acres (16%) of cropland and 15.3 acres (<1%) of pasture in the Shenandoah River tributaries watersheds.

Sheep and Goats

The sheep and goat populations (Table B.7) were estimated from population numbers in the 2007 Agricultural Census for Clarke County, Frederick County, and Warren County. The populations were area-weighted according to pasture areas in each sub-watershed of Shenandoah River tributaries. The sheep and goats were kept on pasture at all times. Sheep and goats are not usually confined and tend not to wade or defecate in the streams. Therefore, the fecal coliform produced by sheep and goats was represented as being deposited directly on pasture.

Pasture in the Shenandoah River tributaries watersheds has average annual sheep and goat manure loadings of 62.1 lb/ac-year. Fecal coliform loadings to the pasture in the Shenandoah River tributaries watersheds from sheep and goats on a daily basis averaged over the year are 8.5 x 10^8 cfu/ac-day.

Table B.7. Sheep and Goat Population in the Shenandoah River tributaries watersheds.

Sub-watershed	Sheep and Goat	Sub-watershed	Sheep and Goat
1	4	17	28
2	35	18	59
3	31	19	37
4	32	20	36
5	24	21	32
6	42	22	1
7	2	23	16
8	25	24	0
9	25	25	0
10	46	26	3
11	13	27	13
12	2	28	13
13	9	29	21
14	4	30	6
15	54	31	9
16	23	Total	645

Horses

Horse populations for the watershed were estimated from population numbers in the 2007 Agricultural Census for Clarke County, Frederick County, and Warren County, and were adjusted considering stakeholder input. The populations were area-weighted according to pasture areas in each sub-watershed of Shenandoah River tributaries (Table B.8). The fecal coliform originating from horses contributes to the pasture load. Fecal coliform loadings from horses on a daily basis averaged over the year and over all pastures in the Shenandoah River tributaries watersheds are estimated as 1.96 x 10^7 cfu/ac-day.

Table B.8. Horse Population in the Shenandoah River tributaries watersheds.

Sub-watershed	Horse	Sub-watershed	Horse
1	5	17	40
2	45	18	101
3	29	19	65
4	33	20	63
5	21	21	135
6	52	22	1
7	2	23	20
8	23	24	0
9	22	25	5
10	65	26	4
11	11	27	17
12	1	28	17
13	8	29	27
14	5	30	7
15	70	31	11
16	30	Total	935

Poultry

The poultry populations (Table B.9) were estimated from population numbers in the 2007 Agricultural Census for Clarke County, Frederick County, and Warren County. The populations were area-weighted according to pasture areas in each sub-watershed of Shenandoah River study area. Manure and fecal coliform production depends on the type of poultry being raised. Broilers produce 0.168 lb/animal/day of manure with 8.90E+07 cfu/animal/day. Layers produce 0.256 lb/animal/day of manure with 1.40E+07 cfu/animal/day. Farmed turkeys produce 0.705 lb/animal/day of manure with 9.30E+07 cfu/animal/day.

Table B.9. Poultry Population in the Shenandoah River tributaries watersheds.

Sub-watershed	Poultry	Sub-watershed	Poultry
1	5	17	28
2	39	18	39
3	40	19	23
4	40	20	22
5	32	21	19
6	49	22	1
7	2	23	18
8	34	24	0
9	34	25	0
10	43	26	4
11	17	27	14
12	1	28	14
13	11	29	24
14	5	30	6
15	61	31	10
16	26	Total	661

Swine

There is a single active swine operation in the Shenandoah River tributaries watersheds. On a typical day, there are 2,000 swine at this operation with an average weight of 150 lb. The maximum number of swine allowed at this operation is 2,100. Swine are kept in confinement all year and produce 1.08E+10 cfu/animal/day, or 0.9 gal/animal/day of liquid manure. The manure is captured and applied on the pasture at a rate of 4,000 gal/acre. Table B.10 shows the fraction of the manure application per month. A second operation is permitted in the study watersheds, but is not active. This operation was included in future conditions for allocation development.

Table B.10. Schedule of liquid swine manure application on pasture.

Month	Liquid swine manure applied (%)*
January	0
February	0
March	0
April	2
May	47
June	11
July	10
August	0
September	0
October	5
November	25
December	0

* As percent of annual production

Wildlife

Wildlife fecal coliform contributions can come from excretion of waste on land and from excretion directly into streams. Information gleaned from the literature and provided by VADGIF and watershed residents was used to estimate wildlife populations. Wildlife species that were found in quantifiable numbers in the watershed included deer, raccoon, muskrat, beaver, wild turkey, goose, and wood duck. Population numbers for each species and fecal coliform amounts were determined along with preferred habitat and habitat area.

Professional judgment was used in estimating the percent of each wildlife species depositing directly into streams, by considering each habitat area occupied (Table B.11), and these numbers were adjusted considering stakeholder input. Fecal loading from wildlife was estimated for each sub-watershed. The wildlife populations were distributed among the sub-watersheds based on the area of appropriate habitat in each sub-watershed. For example, the deer population was evenly distributed across the watershed, whereas muskrat and raccoons had variable population densities based on land use and proximity to a water source. Therefore, a sub-watershed with more stream length and impoundments and more area in crop land use would have more muskrats than a sub-watershed with shorter stream length, fewer impoundments, and less area in crop land use. Estimated distribution of wildlife among sub-watersheds for the Shenandoah River watershed is given in Table B.12.

Table B.11. Wildlife habitat, population density, and direct fecal deposition in streams.

Wildlife type	Habitat and Estimation Method	Population Density (animal / ac - habitat)	Direct fecal deposition in streams (%)
Deer	Entire watershed	0.072 (0.1008 in WS 24 & 25)	1%
Raccoons	low density on forests not in high density area; high density on forest within 600 ft of a permanent water source or 0.5 mile of cropland; highest density in residential areas	Low density: 0.016 High density: 0.047 Highest density: 0.078	10%
Muskrats	8/mile of ditch or medium sized stream intersecting cropland; 4/mile of ditch or medium sized stream intersecting pasture; 5/mile of pond or lake edge	--see habitat column--	25%
Beavers	0.5/mile of perennial streams; and 0.5/mile of lake or pond shore	--see habitat column--	50%
Geese	300 ft buffer around main streams and impoundments	0.069-off season 0.097-peak season	25%
Total Ducks	300 ft buffer around main streams and impoundments	0.016-off season 0.024-peak season	25%
Wild Turkey	Forest; based on kill rate and population model per square mile of forest for each county, assuming the killed birds are 10% of the total population	0.01	1%

Table B.12. Wildlife populations in the Shenandoah River tributaries watersheds.

Sub-watershed	Deer	Raccoon	Muskrat	Beaver	Geese*		Duck*		Wild Turkey
					Off	Peak	Off	Peak	
1	73	43	2	0	11	11	2	2	5
2	228	90	8	1	32	32	7	7	14
3	228	70	9	2	42	42	10	10	12
4	266	106	10	2	41	41	9	9	20
5	191	53	6	1	25	25	6	6	8
6	301	120	10	2	45	45	11	11	17
7	13	5	0	0	4	4	1	1	2
8	184	56	7	2	49	49	8	8	19
9	205	76	10	1	29	29	6	6	6
10	163	34	9	1	27	27	6	6	4
11	163	81	6	1	31	31	7	7	12
12	20	10	1	0	4	4	1	1	2
13	141	64	15	1	30	30	7	7	12
14	20	7	1	0	4	4	1	1	1
15	217	60	7	1	22	22	5	5	4
16	82	13	3	0	8	8	2	2	2
17	107	15	2	0	10	10	2	2	3
18	212	30	12	1	28	28	6	6	4
19	112	23	5	1	14	14	4	4	3
20	122	23	3	0	25	25	3	3	3
21	117	10	4	0	25	25	2	2	1
22	20	9	0	0	2	2	1	1	2
23	255	162	3	0	7	7	1	1	21
24	28	18	0	0	8	8	2	2	0
25	88	56	0	0	17	17	4	4	0
26	67	42	1	0	9	9	2	2	6
27	185	103	2	0	26	26	2	2	16
28	409	183	4	1	19	19	4	4	50
29	176	87	2	0	13	13	3	3	13
30	264	137	2	0	15	15	4	4	28
31	238	137	3	0	18	18	4	4	26
Total	**4,895**	**1,923**	**147**	**18**	**640**	**640**	**133**	**133**	**316**

*Population estimates are provided for off-season (resident) and peak season (resident plus transient).

Other Animals

The Smithsonian Conservation Biology Institute is located in Front Royal, VA in Shenandoah River sub-watershed #27. It is a 3,200-acre park with a number of exotic animal species present. At any one time, the Institute houses approximately 25 small birds, 25 large birds, 204 medium to large-sized mammals and 13 bovine mammals. The animals get their water from an alternative water supply that is not connected to the watershed streams or tributaries. Small birds are not accounted for in bacterial loading estimates. The large birds are considered to be equivalent to geese and added to the sub-watershed #27 geese wildlife population. For the medium to large-sized mammals, which includes wolves, large cats, and hooved animals, an equivalent cattle value is used for bacterial loading. Ten percent of these mammal's waste is assumed to be missed waste and added to the livestock cattle populations, while 90% is assumed to be collected and spread on the Institute's pastures. Bovine mammals are assumed to have the same loading impact as beef cattle and are added to the livestock cattle population directly. Manure from the confined animals is collected and spread across the facility (in certain pastures) on 2-year intervals.

Biosolids

There are numerous fields in the Shenandoah River tributaries watersheds that are permitted to receive biosolids. Fields associated with permits obtained by Milton Wright Trucking, Synagro Central LLC, and Recyc Systems Inc have been actively applied to since 2003. The fields for biosolid application are located in sub-watersheds 10, 15, 16, 17, 18, 19, 20, 21, and 27.

During calibration, the applications were represented in the model based on the application rates and times from the available records, and permitted bacteria concentrations (2,000,000 cfu/dry g). During the allocation period, applications to all fields at worst case scenario application rates and permitted bacteria concentrations (2,000,000 cfu/dry g) were represented in the model to ensure that applications at the 'worst case' permitted limits would be allowable in the watershed. 'Worst case' conditions were assumed, such that all fields with recorded applications during the observed period would be applied to each year. This methodology represents a conservative assumption in support of the implicit margin of safety for the TMDL because most fields are not applied to each year, application rates are typically lower than those assumed for allocation scenarios, and typical bacteria concentrations in treated biosolids are much lower than

2,000,000 cfu/g. The allocation scenario application timing and rates for each sub-watershed are shown in Table B.13.

Table B.13. Simulated application of biosolids for allocation scenarios.

Sub-Watershed	Application Area (acres)	Application Dates	Application Rates (cfu/acre/day)
10	23.85	March 17	5.833E+12
15	90.21	June 30	7.928E+12
		July 31	5.910E+12
		October 31	8.138E+12
16	73.35	April 30	6.191E+11
		May 31	5.130E+10
		June 30	1.854E+12
		July 31	2.013E+12
		September 30	1.289E+12
		October 31	7.825E+12
17	61.16	March 17	9.293E+10
		April 27	5.583E+11
		May 10	1.488E+12
		June 30	3.142E+07
		July 31	4.747E+10
		September 30	1.400E+12
		October 31	1.547E+12
		November 30	1.052E+11
18	189.00	January 31	5.822E+11
		March 31	2.826E+10
		April 27	2.201E+13
		April 30	1.595E+15
		May 10 and 12	2.2E+13
		May 31	1.863E+15
		June 30	2.351E+13
		July 25 and 31	1.9E+13
		August 12	1.940E+13
		August 16	4.229E+13
		August 18	6.440E+13
		August 19	8.590E+13
		August 23	1.078E+14
		August 24	1.301E+14
		August 25	1.520E+14
		August 26	1.701E+14
		August 29	1.822E+14
		August 31	2.065E+14
		September 14	2.259E+14
		September 19	2.682E+14
		September 23	3.324E+14
		September 26	4.180E+14
		September 28	5.256E+14
		September 30	6.552E+14
		October 21	8.065E+14
		October 31	9.757E+14
		November 30	2.206E+13
		December 31	1.386E+11
19	94.00	January 31	2.515E+11
		April 30	4.323E+11
		June 30	1.003E+12
		November 30	2.095E+12

Sub-Watershed	Application Area (acres)	Application Dates	Application Rates (cfu/acre/day)
		December 31	2.944E+12
20	85.20	May 31	2.010E+12
		June 30	6.642E+11
		July 31	1.025E+12
21	39.47	January 31	3.228E+11
		March 31	5.995E+12
		April 30	7.150E+11
		May 25	2.978E+12
		May 27	1.912E+12
		May 31 and June 30	4.968E+11
27	2.41	May 31	5.174E+12

Sanitary Sewer Overflows

During the modeling period, sanitary sewage systems within the Shenandoah River tributaries watersheds sometimes spilled wastewater into the region either due to overflow from heavy storm events. In some instances the spill water had already been treated. Data for these spill events were acquired by the Virginia Department of Environmental Quality (VADEQ). For the purpose of modeling, each event was assumed to last 12 hours, and the flows during the spills ranged from 0.0014 to 0.279 cfs with a fecal coliform loading rate ranging from 1.42E+11 to 2.84E+13 cfu/hr

Appendix C: Model Development

Input Data Requirements

The HSPF model requires a wide variety of input data to describe hydrology, water quality, and land use characteristics of the watershed. The different types and sources of input data used to develop the bacteria TMDLs for the Shenandoah River tributaries watersheds are discussed below.

Surrogate watersheds were used to develop the hydrology models for all eight study watersheds. Hydrology model parameters from the surrogate watershed models were transferred directly to the study watershed models, with the exception of directly-determined parameters describing the watershed such as land use composition, slope, and area.

Climatological Data

Hourly precipitation data were disaggregated from the daily precipitation data using NRCS type III distribution method. Daily precipitation data from NCDC's National Weather Service stations in Front Royal (COOP ID 443229), Mount Weather (COOP ID 445851), and Winchester (COOP ID 449181) were considered for use for the Shenandoah River tributaries watersheds bacteria TMDL development.

To address missing data, the Mount Weather and Winchester stations were used to patch the Front Royal recorded precipitation record. Similarly, data from the Star Tannery (COOP ID 448046) and Mount Weather stations were used to patch gaps in the Winchester precipitation gage record. Also, data from the Lincoln (COOP ID 444909) and The Plains 2 NNE (COOP ID 448396) stations were used to fill gaps in the Mount Weather precipitation gage record.

Based on model performance, the Front Royal precipitation gage data were used in the model for the Happy Creek and Manassas Run watersheds, and the Winchester precipitation gage data were used for the Crooked Run, West Run, Stephens Run, Long Branch, Borden Marsh Run, and Willow Brook watersheds.

Accounting for Withdrawals

Three withdrawals were identified in the study watersheds that potentially influence stream flow rate over time (Table C.1). The withdrawals were modeled varying monthly as shown in the table below. Monthly withdrawal data were used to estimate average daily withdrawal rates for the three facilities. These withdrawals were simulated using WDM time series applied to the specific reach corresponding to the sub-watershed in which each is located.

Table C.1. Withdrawal rates used in modeling the Shenandoah River tributaries.

Facility	Stream Name	Historical monthly withdrawals (MG)	Withdrawal rates used for modeling (MGD[1])
Stephens City Quarries	Stephens Run	45.5 -73.2	1.47 – 2.36
Town of Front Royal WTP – Happy Crk. Intake	Happy Creek	0.0[2]	0.0[2]
Town of Front Royal WTP – Sloan Crk. Intake	Sloan Creek	3.3 – 5.2	0.11 – 0.17

[1] million gallons per day
[2] No withdrawals were recorded in the period of record provided by DEQ

Surrogate Analysis

An analysis was performed to identify suitable watersheds to serve as hydrology surrogates for the study watersheds. This analysis sought to identify gaged watersheds that exhibit similar characteristics with regard to location, size, land use composition, ecoregion, soils, and slope to develop hydrology models from which to draw model parameters. Given the fact that karst geology is present in the study watersheds, affecting their hydrologic response, location (proximity to the study watersheds) and ecoregion were given particularly high consideration in this analysis.

Regarding proximity, potential surrogate watersheds were identified for consideration using USGS stream flow gages within 25 miles of the study watersheds. Land use composition was determined using the same land use data for all watersheds (2012 NASS data including 2006 NLCD). Ecoregion considers the dominant ecoregion(s) as well as the sub-region(s) overlaying each watershed. Soil hydrologic group, as determined using USDA STATSGO data, was considered in the analysis. Average slope throughout the watershed was derived from 30-meter grid digital elevation model (DEM) data.

Initial analysis identified sixteen potential surrogate watersheds, which was pared down to three suitable surrogates for the study watersheds. The three identified potential surrogate watersheds, associated flow gages, and the study watersheds are identified in Figure C.1.

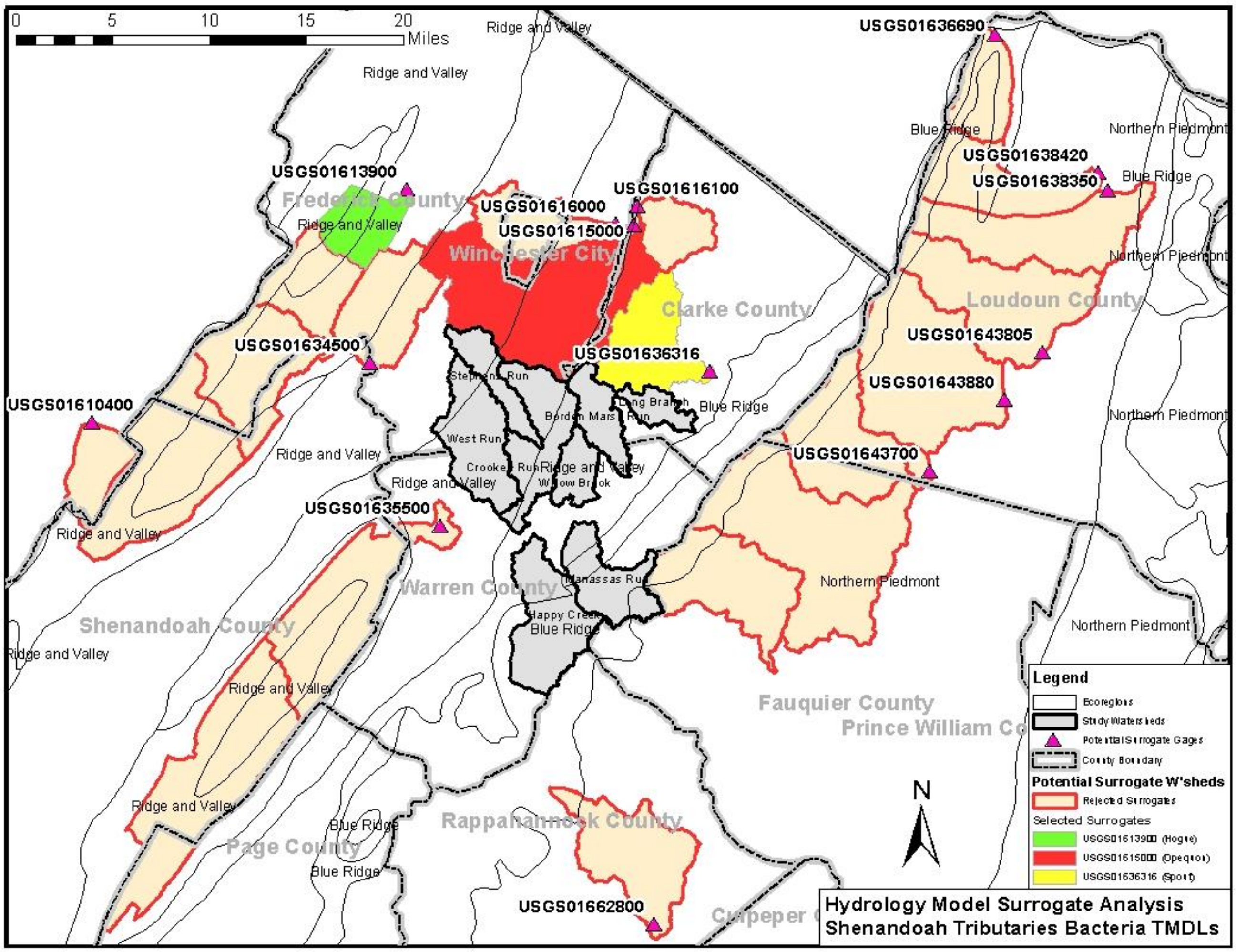


Figure C.1. Shenandoah River tributaries, potential surrogates, and suitable surrogates watersheds considered in the hydrology surrogate analysis.

Table C.2 contains descriptions of the study watersheds and the three potential surrogate watersheds. Initially, groups of study watersheds with similar characteristics were matched with the potential hydrology surrogate with the most similar characteristics. However, upon review of the surrogate matches and preliminary hydrology model development from the potential surrogate watershed models by the Technical Advisory Committee, it was decided that the Spout Run watershed serve as the hydrology surrogate for all eight study watersheds.

Table C.2. Characteristics of the study and potential surrogate watersheds considered in hydrology surrogate analysis.

Stream Name	Distance to Study Area	Ecoregion	Area (mi^2)	Land Use Composition			STATSGO Hydrology Group	Slope %
				Forest	Ag	Dev		
Happy Creek	---	Blue Ridge (Northern Igneous Ridges) AND Ridge & Valley (Norther Limestone/Dolomite Valleys)	22.10	66.6%	11.6%	21.3%	C	17.60
Manassas Run	---	Blue Ridge (Northern Igneous Ridges) AND Ridge & Valley (Norther Limestone/Dolomite Valleys)	14.74	71.3%	13.3%	14.8%	B	17.11
Crooked Run	---	Ridge & Valley (Northern Shale Valleys)	47.27	43.7%	40.7%	13.5%	C	9.39
West Run	---	Ridge & Valley (Northern Shale Valleys)	19.84	42.0%	48.9%	8.2%	C	10.20
Stephens Run	---	Ridge & Valley (Northern Shale Valleys)	8.74	24.3%	57.2%	17.6%	C	8.17
Long Branch	---	Ridge & Valley (Norther Limestone/Dolomite Valleys)	5.20	14.1%	81.7%	4.1%	B	6.40
Willow Brook	---	Ridge & Valley (Norther Limestone/Dolomite Valleys)	6.92	17.6%	69.7%	12.6%	B	6.54
Borden Marsh Run	---	Ridge & Valley (Norther Limestone/Dolomite Valleys)	9.38	14.7%	78.4%	6.2%	B	5.64
Hogue Creek	6.2	Ridge & Valley (Northern Shale Valleys)	12.3	76.9%	11.3%	11.4%	B	16.3
Opequon Creek	0.0	Ridge & Valley (Norther Limestone/Dolomite Valleys)	58.2	30.0%	47.2%	21.9%	C	7.3
Spout Run	0.0	Ridge & Valley (Norther Limestone/Dolomite Valleys)	21.4	24.9%	66.3%	8.3%	B & C	5.1

Spring Flows Analysis

The HSPF model is effective at simulating watershed hydrology in a variety of geological conditions. However, the study watersheds are located in an area largely underlain by karst geology. Watersheds with such karst presence often exhibit a more sustained baseflow due to spring discharges. This condition is particularly important as it relates to low flow conditions, which can directly affect violation rates in watersheds with significant directly-deposited fecal bacteria loads. Springs present in the study watersheds were identified, characterized, and incorporated into the study watershed hydrology models to ensure that low-flow conditions were properly represented.

Field reconnaissance was performed by the project team in fall 2013, USGS publications characterizing hydrogeology in Clarke, Frederick, and Warren counties were reviewed, and a visual review of USGS 7.5-minute topographic quad maps was conducted to identify springs in the study watersheds. The project team was also made aware of a springs database developed and maintained by DEQ's Ground Water Characterization Program. A copy of this database for the study area was provided by DEQ, and used to complete the identification of springs in the study watersheds.

The springs were characterized to estimate a representative low flow discharge value. The estimated low flow values were summed for all the springs identified within each sub-watershed, and that value was used to estimate spring flow to that stream reach in the model in low flow conditions as a constant value.

Model Parameters

The hydrology parameters required by HSPF were defined for every land use category using watershed-specific values and values from the surrogate watershed (Spout Run) model. Required hydrology parameters are listed in the HSPF Version 12 User's Manual (Bicknell et al., 2005). Values for required hydrology parameters for the Shenandoah River tributaries watersheds generally comply with guidance in BASINS Technical Note 6 (USEPA, 2000) unless otherwise noted. Each reach requires a function table (FTABLE) to describe the relationship between water depth, surface area, volume, and discharge (Bicknell et al., 2005). Stream lengths and slopes were determined using GIS data. The procedures described in Staley et al. (2006) were used to characterize the reaches in the Shenandoah River tributaries watersheds using NRCS bankfull equations and digital elevation models. Information on the calculated stream geometry for each sub-watershed is presented in Table C.3 for the bankfull conditions. Final hydrology model parameter values are described in

Table C.4.

Table C.3. Reach characteristics for the Shenandoah River tributaries watersheds.

Sub-watershed	Stream length (mile)	Average bankfull width (ft)	Average bankfull channel depth (ft)	Slope (ft/ft)
1	2.55	112	23.0	0.0017
2	1.76	36	24.6	0.0024
3	6.16	85	4.9	0.0079
4	3.16	105	8.2	0.0064
5	3.17	56	6.6	0.0077
6	4.02	131	13.1	0.0018
7	1.00	69	9.8	0.0039
8	4.38	66	13.1	0.0064
9	1.47	56	13.1	0.0039
10	1.71	66	13.1	0.0026
11	3.58	62	9.8	0.0090
12	0.95	72	6.6	0.0153
13	2.51	98	6.6	0.0080
14	0.79	105	13.1	0.0183
15	1.65	52	13.1	0.0050
16	1.66	190	6.6	0.0033
17	2.94	56	11.5	0.0084
18	2.76	59	9.8	0.0029
19	1.49	49	8.2	0.0046
20	2.35	39	9.8	0.0081
21	1.52	36	8.2	0.0082
22	0.64	121	13.1	0.0062
23	5.24	56	9.8	0.0260
24	0.66	69	13.1	0.0077
25	1.48	30	19.7	0.0102
26	1.92	39	16.4	0.0173
27	2.84	52	9.8	0.0330
28	3.85	46	11.5	0.0312
29	2.57	92	13.1	0.0124
30	3.07	59	9.8	0.0138
31	2.91	52	9.8	0.0315

Table C.4. Hydrology parameters for the Shenandoah River tributaries watersheds.

Parameter	Definition	Units	FINAL Values	FUNCTION OF…	Appendix C Table (if applicable)
PERLND					
		PWAT-PARM2			
FOREST	Fraction forest cover	none	0.0 - 1.0	Forest cover	
LZSN	Lower zone nominal soil moisture storage	inches	7.2	Soil properties	
INFILT	Index to infiltration capacity	in/hr	0.251	Soil and cover conditions	
LSUR	Length of overland flow	feet	100 - 700	Topography	
SLSUR	Slope of overland flowplane	none	0.0095 – 0.2551	Topography	
KVARY	Groundwater recession variable	1/in	3.5	Calibrate	
AGWRC	Base groundwater recession	none	0.995	Calibrate	
		PWAT-PARM3			
PETMAX	Temp below which ET is reduced	deg. F	45	Climate, vegetation	
PETMIN	Temp below which ET is set to zero	deg. F	35	Climate, vegetation	
INFEXP	Exponent in infiltration equation	none	2	Soil properties	
INFILD	Ratio of max/mean infiltration capacities	none	2	Soil properties	
DEEPFR	Fraction of GW inflow to deep recharge	none	0.9 for subsheds #1 – #13, 0.45 for subshed #14 – #31	Geology	
BASETP	Fraction of remaining ET from baseflow	none	0.075	Riparian vegetation	
AGWETP	Fraction of remaining ET from active GW	none	0.01	Marsh/wetlands ET	
		PWAT-PARM4			
CEPSC	Interception storage capacity	inches	monthly[a]	Vegetation	
UZSN	Upper zone nominal soil moisture storage	inches	monthly[a]	Soil properties	
NSUR	Mannings' n (roughness)	none	0.15	Land use, surface condition	
INTFW	Interflow/surface runoff partition parameter	none	3.0	Soils, topography, land use	
IRC	Interfiow recession parameter	none	0.48	Soils, topography, land use	
LZETP	Lower zone ET parameter	none	monthly[a]	Vegetation	
IMPLND					

Parameter	Definition	Units	FINAL Values	FUNCTION OF…	Appendix C Table (if applicable)
IWAT-PARM2					
LSUR	Length of overland flow	feet	100	Topography	
SLSUR	Slope of overland flowplane	none	0.226	Topography	
NSUR	Mannings' n (roughness)	none	0.1	Land use, surface condition	
RETSC	Retention/inter-ception storage capacity	inches	0.065	Land use, surface condition	
IWAT-PARM3					
PETMAX	Temp below which ET is reduced	deg. F	40	Climate, vegetation	
PETMIN	Temp below which ET is set to zero	deg. F	35	Climate, vegetation	
RCHRES					
HYDR-PARM2					
KS	Weighting factor for hydraulic routing		0.5		

[a]Varies by month and with land use
[a]Values varied by soil type (available on request).
[b]Values varied by month and with land use (available on request).

Accounting for Pollutant Sources

Overview

There are 101 single family domestic sewage discharge sources. During calibration and validation, reported bacteria concentrations discharged by these facilities were used as input to the model. During future conditions, loads from the facilities were modeled at their design flows and bacteria concentrations at their permitted limits (126 cfu/100 mL) (Table C.5).

Table C.5. General permits in the Shenandoah River tributaries watersheds.

Permit Number	Facility Name	Sub water -shed	Design Flow (mgd*)	Permitted *E. coli* Conc. (cfu/100 mL)	*Permitted E. coli* Load (cfu/year)
VAG401231	Single Family Home	1	0.001	126	1.74×10^{9}
VAG401901	Single Family Home	1	0.001	126	1.74×10^{9}
VAG401790	Single Family Home	1	0.001	126	1.74×10^{9}
VAG408403	Single Family Home	2	0.001	126	1.74×10^{9}
VAG401816	Single Family Home	2	0.001	126	1.74×10^{9}

Permit Number	Facility Name	Sub water -shed	Design Flow (mgd*)	Permitted *E. coli* Conc. (cfu/100 mL)	*Permitted E. coli* Load (cfu/year)
VAG401563	Single Family Home	2	0.001	126	1.74×10^9
VAG401181	Single Family Home	2	0.001	126	1.74×10^9
VAG401706	Single Family Home	2	0.001	126	1.74×10^9
VAG401079	Single Family Home	2	0.001	126	1.74×10^9
VAG408207	Single Family Home	2	0.001	126	1.74×10^9
VAG408206	Single Family Home	2	0.001	126	1.74×10^9
VAG408250	Single Family Home	2	0.001	126	1.74×10^9
VAG401640	Single Family Home	2	0.001	126	1.74×10^9
VAG401845	Single Family Home	3	0.001	126	1.74×10^9
VAG401139	Single Family Home	3	0.001	126	1.74×10^9
VAG401587	Single Family Home	3	0.001	126	1.74×10^9
VAG401189	Single Family Home	3	0.001	126	1.74×10^9
VAG408069	Single Family Home	3	0.001	126	1.74×10^9
VAG401846	Single Family Home	3	0.001	126	1.74×10^9
VAG408044	Single Family Home	3	0.001	126	1.74×10^9
VAG401698	Single Family Home	3	0.001	126	1.74×10^9
VAG401902	Single Family Home	3	0.001	126	1.74×10^9
VAG401793	Single Family Home	3	0.001	126	1.74×10^9
VAG401717	Single Family Home	3	0.001	126	1.74×10^9
VAG401484	Single Family Home	3	0.001	126	1.74×10^9
VAG401888	Single Family Home	3	0.001	126	1.74×10^9
VAG401185	Single Family Home	3	0.001	126	1.74×10^9
VAG401843	Single Family Home	4	0.001	126	1.74×10^9
VAG401131	Single Family Home	4	0.001	126	1.74×10^9
VAG401245	Single Family Home	4	0.001	126	1.74×10^9

Permit Number	Facility Name	Sub water -shed	Design Flow (mgd*)	Permitted *E. coli* Conc. (cfu/100 mL)	*Permitted E. coli* Load (cfu/year)
VAG401470	Single Family Home	4	0.001	126	1.74×10^9
VAG401247	Single Family Home	4	0.001	126	1.74×10^9
VAG401456	Single Family Home	4	0.001	126	1.74×10^9
VAG408278	Single Family Home	4	0.001	126	1.74×10^9
VAG401491	Single Family Home	4	0.001	126	1.74×10^9
VAG408246	Single Family Home	4	0.001	126	1.74×10^9
VAG408277	Single Family Home	4	0.001	126	1.74×10^9
VAG408245	Single Family Home	4	0.001	126	1.74×10^9
VAG401693	Single Family Home	4	0.001	126	1.74×10^9
VAG401847	Single Family Home	4	0.001	126	1.74×10^9
VAG401047	Single Family Home	4	0.001	126	1.74×10^9
VAG401073	Single Family Home	4	0.001	126	1.74×10^9
VAG401630	Single Family Home	5	0.001	126	1.74×10^9
VAG408308	Single Family Home	5	0.001	126	1.74×10^9
VAG401776	Single Family Home	5	0.001	126	1.74×10^9
VAG401370	Single Family Home	5	0.001	126	1.74×10^9
VAG401284	Single Family Home	5	0.001	126	1.74×10^9
VAG401662	Single Family Home	5	0.001	126	1.74×10^9
VAG401906	Single Family Home	5	0.001	126	1.74×10^9
VAG401252	Single Family Home	5	0.001	126	1.74×10^9
VAG401600	Single Family Home	5	0.001	126	1.74×10^9
VAG401333	Single Family Home	5	0.001	126	1.74×10^9
VAG408398	Single Family Home	6	0.001	126	1.74×10^9
VAG401624	Single Family Home	6	0.001	126	1.74×10^9
VAG401813	Single Family Home	6	0.001	126	1.74×10^9

Permit Number	Facility Name	Sub water -shed	Design Flow (mgd*)	Permitted *E. coli* Conc. (cfu/100 mL)	*Permitted E. coli* Load (cfu/year)
VAG401294	Single Family Home	6	0.001	126	1.74×10^9
VAG401924	Single Family Home	8	0.001	126	1.74×10^9
VAG401229	Single Family Home	8	0.001	126	1.74×10^9
VAG401986	Single Family Home	8	0.001	126	1.74×10^9
VAG401758	Single Family Home	8	0.001	126	1.74×10^9
VAG401759	Single Family Home	8	0.001	126	1.74×10^9
VAG401760	Single Family Home	8	0.001	126	1.74×10^9
VAG401761	Single Family Home	8	0.001	126	1.74×10^9
VAG401420	Single Family Home	8	0.001	126	1.74×10^9
VAG401908	Single Family Home	8	0.001	126	1.74×10^9
VAG401250	Single Family Home	8	0.001	126	1.74×10^9
VAG401757	Single Family Home	8	0.001	126	1.74×10^9
VAG401508	Single Family Home	8	0.001	126	1.74×10^9
VAG401373	Single Family Home	8	0.001	126	1.74×10^9
VAG401526	Single Family Home	10	0.001	126	1.74×10^9
VAG401765	Single Family Home	11	0.001	126	1.74×10^9
VAG401778	Single Family Home	11	0.001	126	1.74×10^9
VAG401070	Single Family Home	11	0.001	126	1.74×10^9
VAG401783	Single Family Home	11	0.001	126	1.74×10^9
VAG401781	Single Family Home	11	0.001	126	1.74×10^9
VAG401107	Single Family Home	11	0.001	126	1.74×10^9
VAG401777	Single Family Home	11	0.001	126	1.74×10^9
VAG401120	Single Family Home	11	0.001	126	1.74×10^9
VAG401730	Single Family Home	11	0.001	126	1.74×10^9
VAG401782	Single Family Home	11	0.001	126	1.74×10^9

Permit Number	Facility Name	Sub water -shed	Design Flow (mgd*)	Permitted *E. coli* Conc. (cfu/100 mL)	*Permitted E. coli* Load (cfu/year)
VAG401539	Single Family Home	11	0.001	126	1.74×10^9
VAG401779	Single Family Home	11	0.001	126	1.74×10^9
VAG401215	Single Family Home	11	0.001	126	1.74×10^9
VAG401575	Single Family Home	11	0.001	126	1.74×10^9
VAG401978	Single Family Home	11	0.001	126	1.74×10^9
VAG401015	Single Family Home	13	0.001	126	1.74×10^9
VAG401112	Single Family Home	13	0.001	126	1.74×10^9
VAG408427	Single Family Home	13	0.001	126	1.74×10^9
VAG401151	Single Family Home	13	0.001	126	1.74×10^9
VAG401050	Single Family Home	13	0.001	126	1.74×10^9
VAG408018	Single Family Home	13	0.001	126	1.74×10^9
VAG401460	Single Family Home	13	0.001	126	1.74×10^9
VAG401056	Single Family Home	15	0.001	126	1.74×10^9
VAG401854	Single Family Home	19	0.001	126	1.74×10^9
VAG401755	Single Family Home	30	0.001	126	1.74×10^9
VAG401880	Single Family Home	30	0.001	126	1.74×10^9
VAG401771	Single Family Home	30	0.001	126	1.74×10^9
VAG401639	Single Family Home	31	0.001	126	1.74×10^9
VAG401754	Single Family Home	31	0.001	126	1.74×10^9
VAG401673	Single Family Home	31	0.001	126	1.74×10^9
VAG401578	Single Family Home	31	0.001	126	1.74×10^9

*million gallons per day

Bacteria loads that are deposited by cattle, wildlife, and straight pipes directly into streams were treated as direct nonpoint sources in the model. Direct nonpoint source loadings were applied to the stream reach in each sub-watershed as appropriate. The point sources permitted to discharge bacteria in the watershed were incorporated into the simulations at the stream locations designated in their permits.

Bacteria that were deposited on land were treated as nonpoint source loadings; all or part of that load may be transported to the stream as a result of surface runoff during rainfall events. The nonpoint source loading was applied in the model in the form of fecal coliform counts to individual land use categories by sub-watershed. Bacterial die-off on the land surface and in the stream was simulated within the model. Both direct nonpoint and nonpoint source loadings were varied by month to account for seasonal differences in bacteria production and deposition characteristics, such as migratory behavior, management practices, and cattle time in streams.

The Bacteria Source Load Calculator (Zeckoski et al., 2005) was used to generate nonpoint source fecal coliform inputs to the HSPF model. This spreadsheet program takes inputs of animal numbers, land use, and management practices by sub-watershed and outputs hourly direct deposition to streams and monthly loads to each land use type. The BSLC allows direct deposition in the stream by cattle and waterfowl to occur only during daylight hours.

Modeling fecal coliform die-off

Fecal coliform die-off was modeled using first order die-off of the form:

$$C_t = C_o 10^{-kt}$$

Where: C_t = concentration or load at time t;

C_o = starting concentration or load;

k = decay rate (day^{-1}); and

t = time in days.

A review of literature provided estimates of decay rates that could be applied to waste storage and handling in the Shenandoah River watershed (Table C.6).

Table C.6 First order decay rates for different animal waste storage as affected by storage/application conditions and their sources.

Waste type	Storage/application	Decay rate (day^{-1})	Reference
Dairy Manure	Pile (not covered)	0.066	Crane and Moore (1986)
	Pile (covered)	0.028	
Beef manure	Anaerobic lagoon	0.375	Crane and Moore (1986)
Poultry litter	Soil surface	0.035	Giddens *et al*. (1973)
		0.342	Crane *et al*. (1980)

Based on the values cited in the literature, the following decay rates were used in simulating fecal coliform die-off in stored waste.

- Liquid dairy manure: Because the decay rate for liquid dairy manure storage could not be found in the literature, the decay rate for beef manure in anaerobic lagoons (0.375 day^{-1}) was used.
- Solid cattle manure: Based on the range of decay rates (0.028 - 0.066 day^{-1}) reported for solid dairy manure, a decay rate of 0.05 day^{-1} was used, assuming that a majority of manure piles are not covered.

Depending on the duration of storage, type of storage, type of manure, and die-off factor, the fraction of fecal coliform surviving in the manure at the end of storage is calculated. While calculating survival fraction at the end of the storage period, the daily addition of manure and coliform die-off of each fresh manure addition is considered to arrive at an effective survival fraction over the entire storage period. The amount of fecal coliform available for application to land per year is estimated by multiplying the survival fraction with total fecal coliform produced per year (in as-excreted manure). Monthly fecal coliform application to land is estimated by multiplying the amount of fecal coliform available for application to land per year by the fraction of manure applied to land during that month. A base-10 decay rate of 0.05 day^{-1} was assumed for fecal coliform on the land surface. The decay rate of 0.05 day^{-1} is represented in HSPF by specifying a maximum surface buildup of nine times the daily loading rate. An in-stream decay rate of 1.15 day^{-1} were used for the Shenandoah River main stem and tributaries.

Modeling Nonpoint Sources

For modeling purposes, nonpoint fecal coliform loads were those that were deposited or applied to land, and hence, required surface runoff events for transport to streams. Fecal coliform loading by land use for all sources in each sub-watershed is presented in Chapter 3. The existing condition fecal coliform loads are based on best estimates of existing wildlife, livestock, and human populations and fecal coliform production rates. Fecal coliform in stored waste was adjusted for die-off prior to the time of land application when calculating loadings to cropland and pasture. For a given period of storage, the total amount of fecal coliform present in the stored manure was adjusted for die-off on a daily basis. The sources of fecal coliform to different land use categories and how the model handled them are briefly discussed below.

1. Cropland and Hay land: Liquid and solid manure is applied to cropland and hay land as described in Chapter 3. Fecal coliform loadings to cropland were adjusted to account for die-off during storage and partial incorporation during land application. Wildlife contributions were also added to the cropland and hay land areas. For modeling, the monthly fecal coliform loading assigned to cropland was distributed over the entire cropland acreage within a sub-watershed. Thus, loading rate varied by month and sub-watershed.
2. Pasture: In addition to direct deposition from livestock and wildlife, pastures receive applications of solid manure as described in Chapter 3. Applied fecal coliform loading to pasture was reduced to account for die-off during storage. For modeling, the monthly fecal coliform loading assigned to pasture was distributed over the entire pasture acreage within a sub-watershed.
3. Residential: Fecal coliform loading on rural residential land uses came from failing septic systems and waste from pets. In the model simulations, fecal coliform loads produced by failing septic systems and pets in a sub-watershed were assumed to be uniformly applied to the residential pervious land use areas in each sub-watershed. Pet loads varied by sub-watershed but were constant throughout the year. Impervious areas received constant loads of 1.0 x 10^7 cfu/acre/day.

4. Forest: Wildlife not defecating in streams, cropland, or pastures provided fecal coliform loading to the forested land use. These loadings varied by month (to account for migration and hibernation) and by sub-watershed.

Modeling Direct Nonpoint Sources

Fecal coliform loads from direct nonpoint sources included cattle in streams, wildlife in streams, and direct loading to streams from straight pipes from residences and sewage spills. Loads from direct nonpoint sources in each sub-watershed are described in detail in Chapter 3. Contributions of fecal coliform from interflow and groundwater were modeled with a constant concentration of 8 cfu/100mL for interflow and 4 cfu/100mL for groundwater for most of the watershed.

Bacteria Results: Calibration and Validation

Figures C.2 through C.10 show the daily maxima, minima, and averages of simulated values for the final calibration runs for the *E. coli* data at stations 1BBMR000.20, 1BCRO002.75, 1BHPY001.29, 1BHPY002.67, 1BLNG000.24, 1BMAN002.55, 1BSTV000.20, 1BWST000.20, and 1BWLO000.71, respectively. Figures C.11 through C.16 show the daily maxima, minima, and averages of simulated values for the final validation runs for the *E. coli* data at stations 1BBMR000.20, 1BCRO002.75, 1BLNG000.24, 1BSTV000.20, 1BWST000.20, and 1BWLO000.71, respectively. The final calibrated water quality parameters are given in Table C.7.

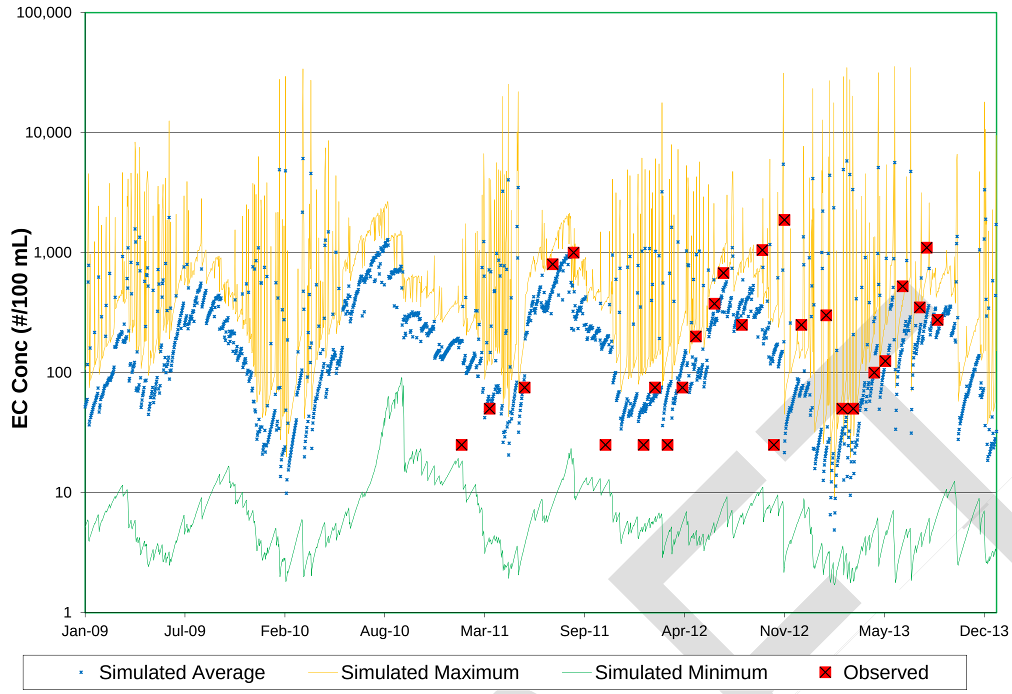


Figure C.2. Observed E. coli data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Borden Marsh Run at station 1BBMR000.20 for the calibration period (January 1, 2009 – December 31, 2013).

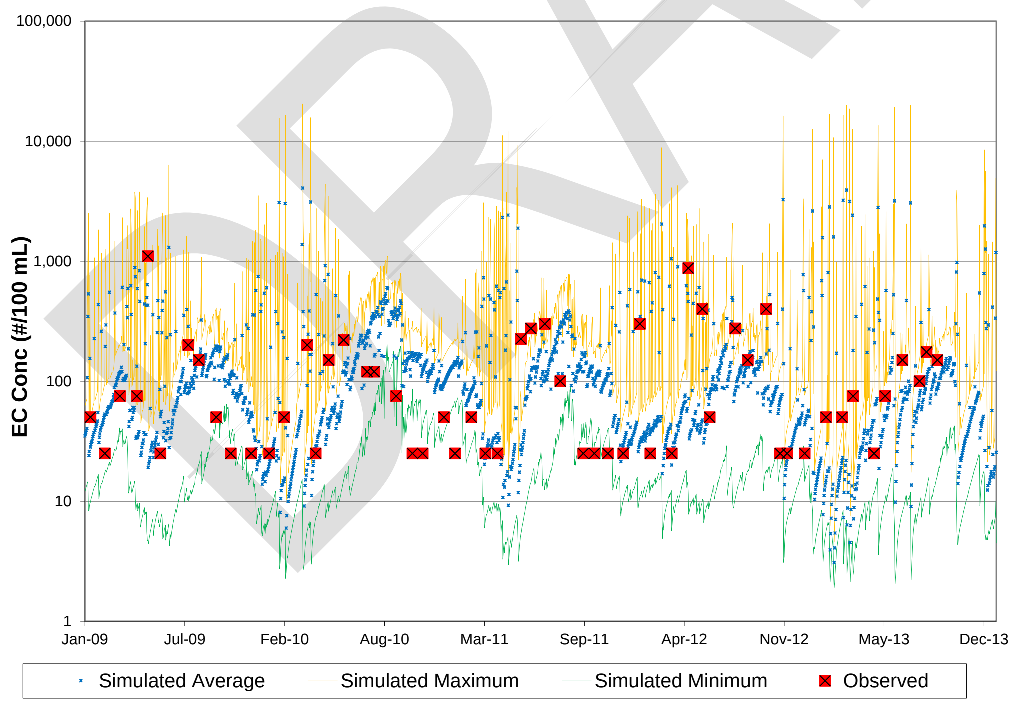


Figure C.3. Observed E. coli data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Crooked Run at station 1BCRO002.75 for the calibration period (January 1, 2009 – December 31, 2013).

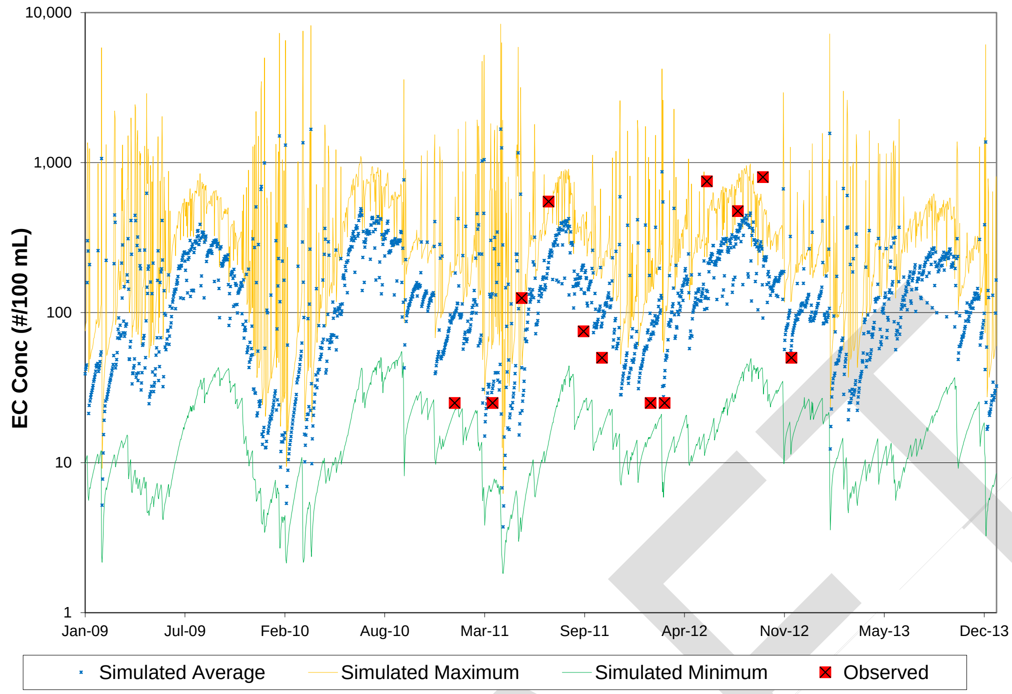


Figure C.4. Observed E. coli data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Happy Creek at station 1BHPY001.29 for the calibration period (January 1, 2009 – December 31, 2013).

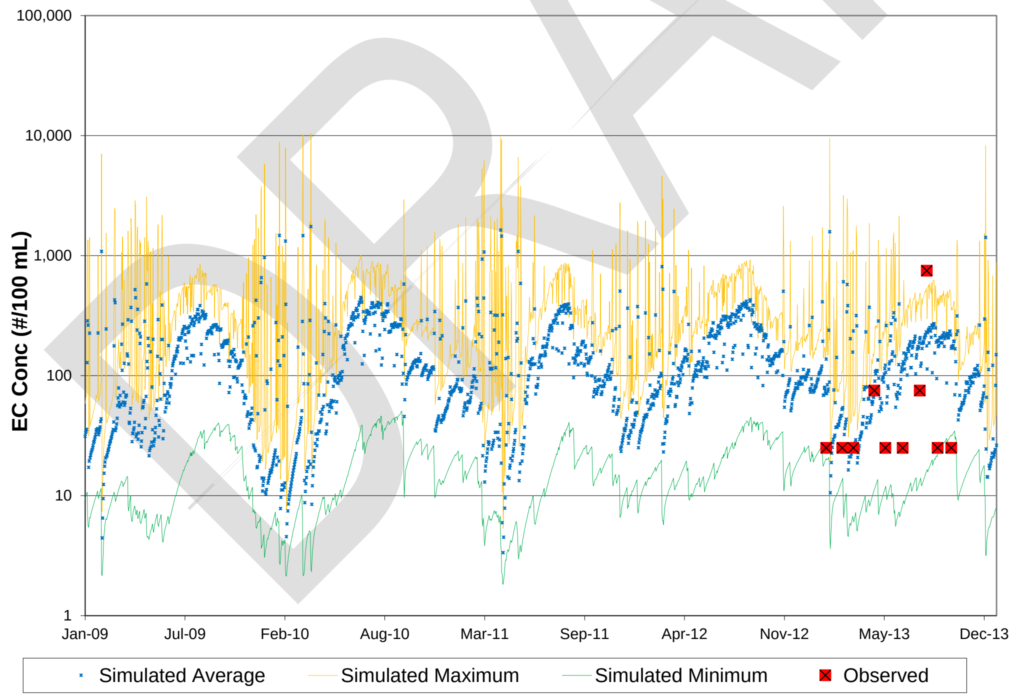


Figure C.5. Observed E. coli data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Happy Creek at station 1BHPY002.67 for the calibration period (January 1, 2009 – December 31, 2013).

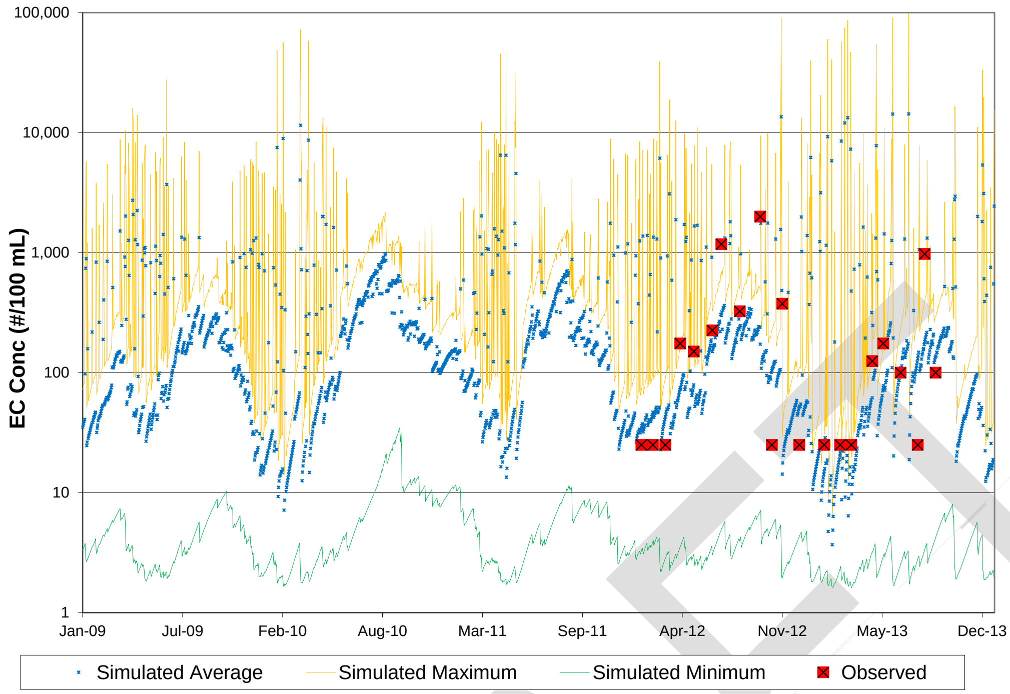


Figure C.6. Observed E. coli data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Long Branch at station 1BLNG000.24 for the calibration period (January 1, 2009 – December 31, 2013).

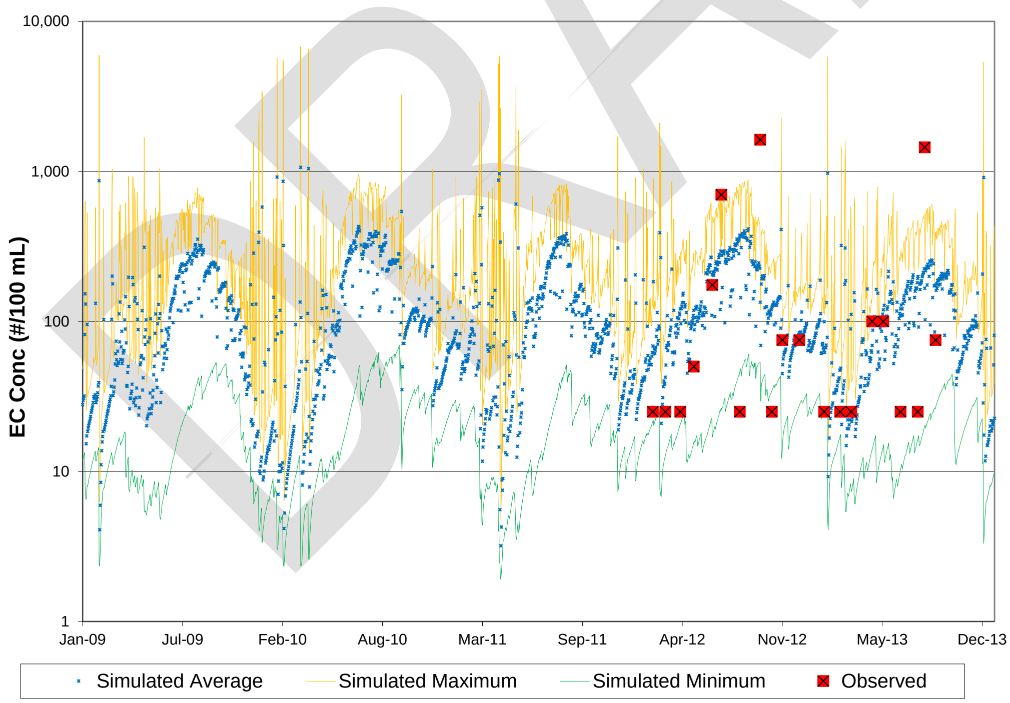


Figure C.7. Observed E. coli data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Manassas Run at station 1BMAN002.55 for the calibration period (January 1, 2009 – December 31, 2013).

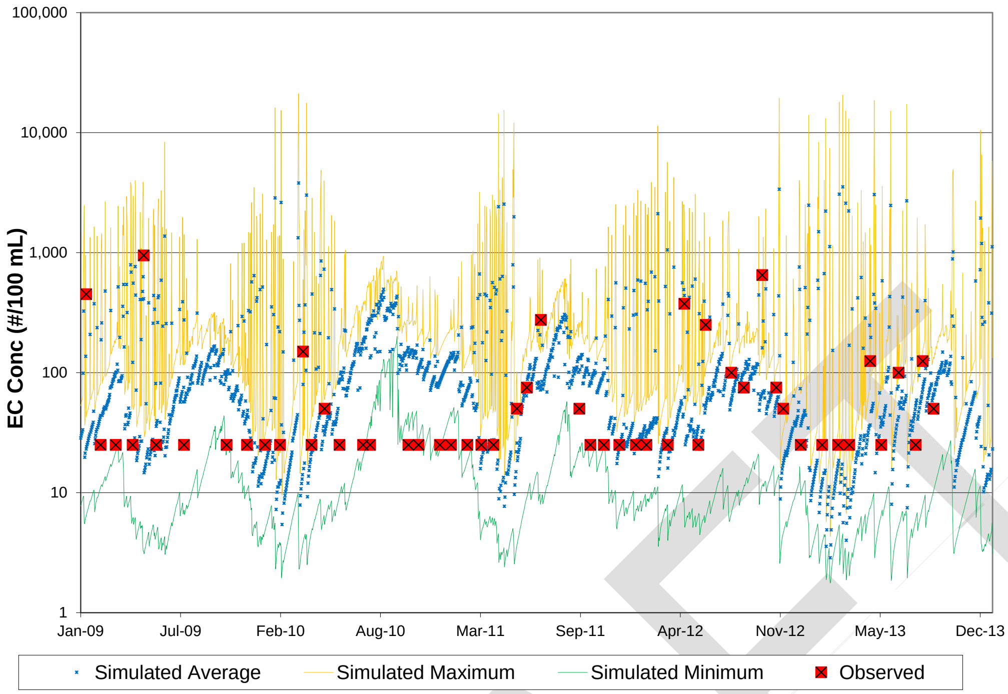


Figure C.8. Observed E. coli data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Stephens Run at station 1BSTV000.20 for the calibration period (January 1, 2009 – December 31, 2013).

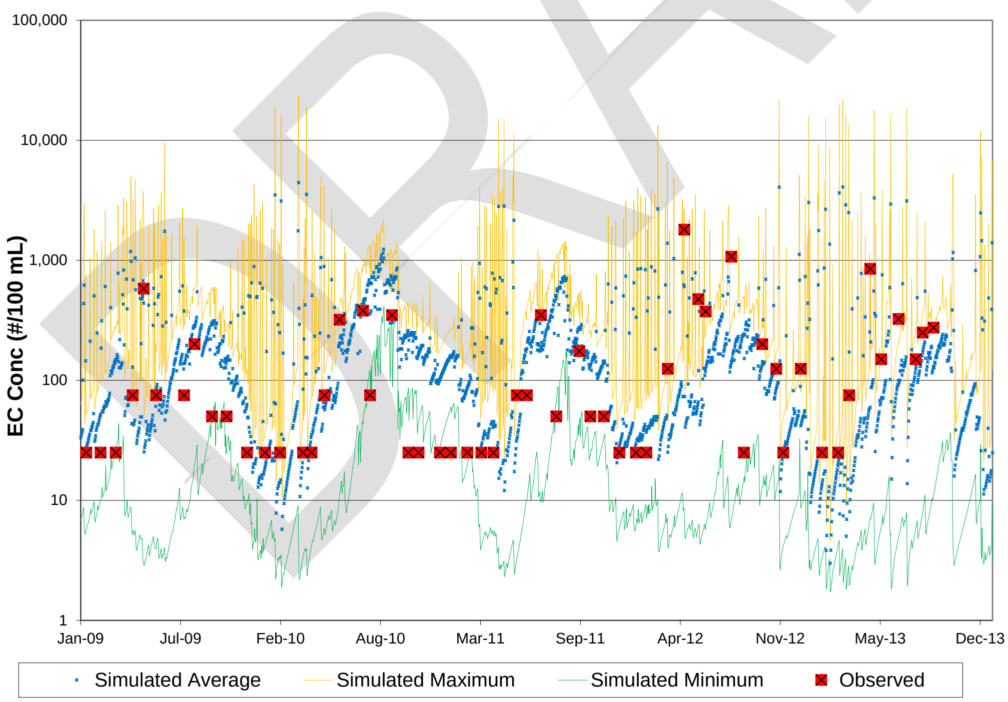


Figure C.9. Observed E. coli data plotted with the daily maximum, minimum, and average simulated fecal coliform values for West Run at station 1BWST000.20 for the calibration period (January 1, 2009 – December 31, 2013).

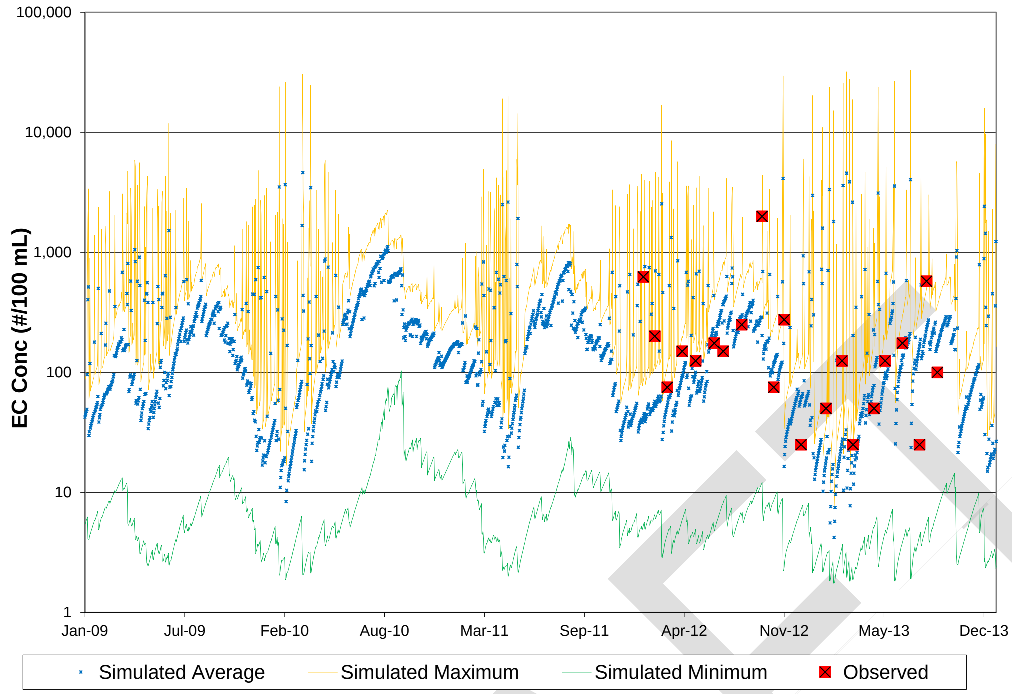


Figure C.10. Observed E. coli data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Willow Brook at station 1BWLO000.71 for the calibration period (January 1, 2009 – December 31, 2013).

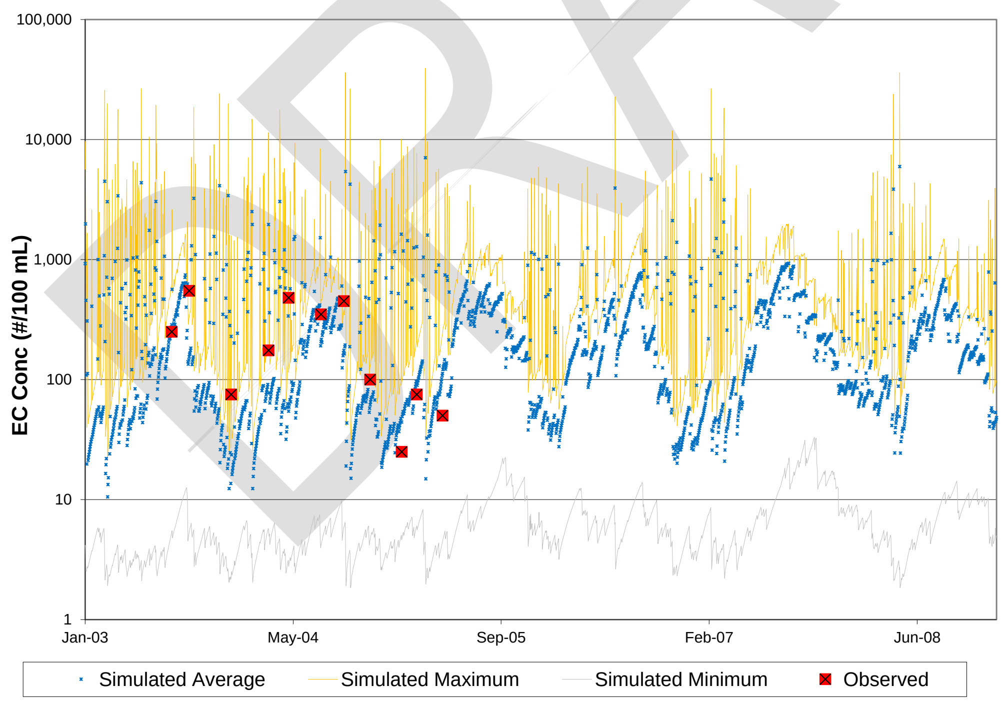


Figure C.11. Observed E. coli data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Borden Marsh Run at station 1BBMR000.20 for the validation period (January 1, 2003 – December 31, 2008).

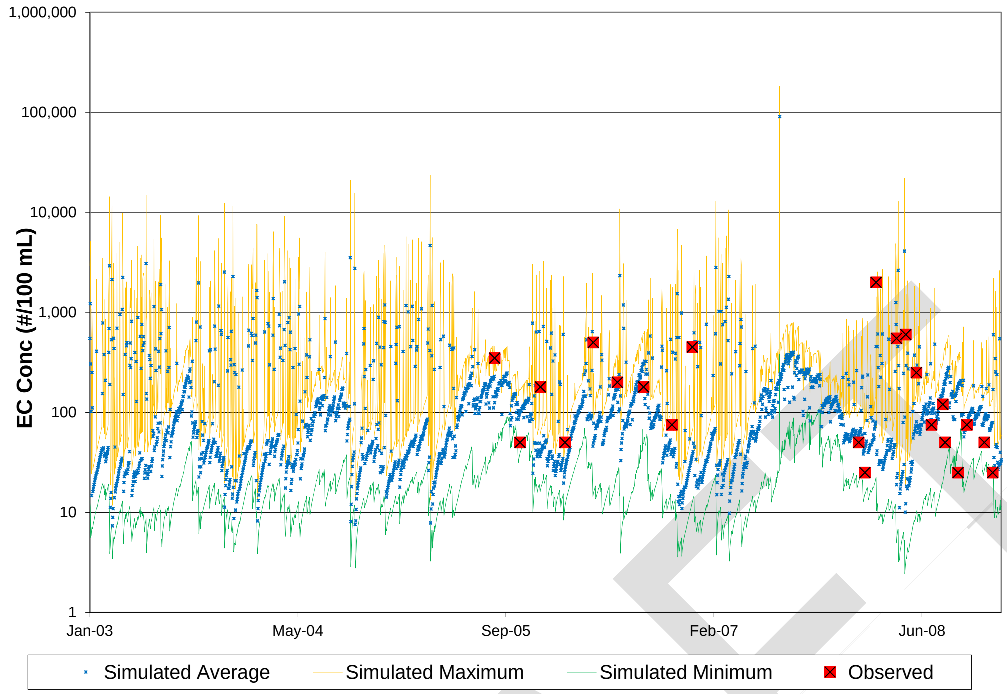


Figure C.12. Observed E. coli data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Crooked Run at station 1BCRO002.75 for the validation period (January 1, 2003 – December 31, 2008).

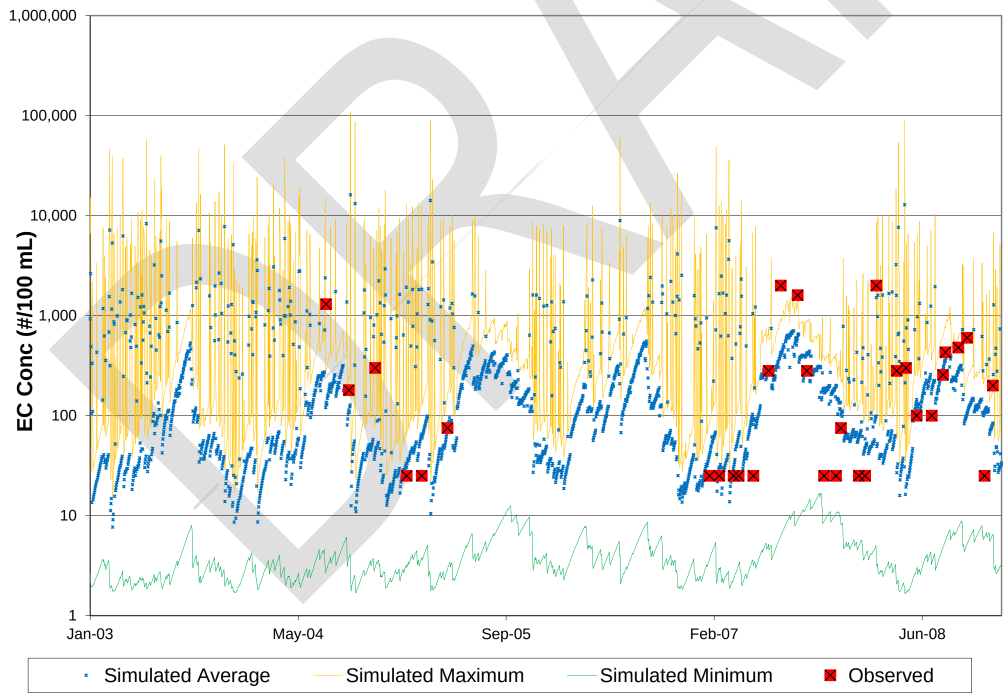


Figure C.13. Observed E. coli data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Long Branch at station 1BLNG000.24 for the validation period (January 1, 2003 – December 31, 2008).

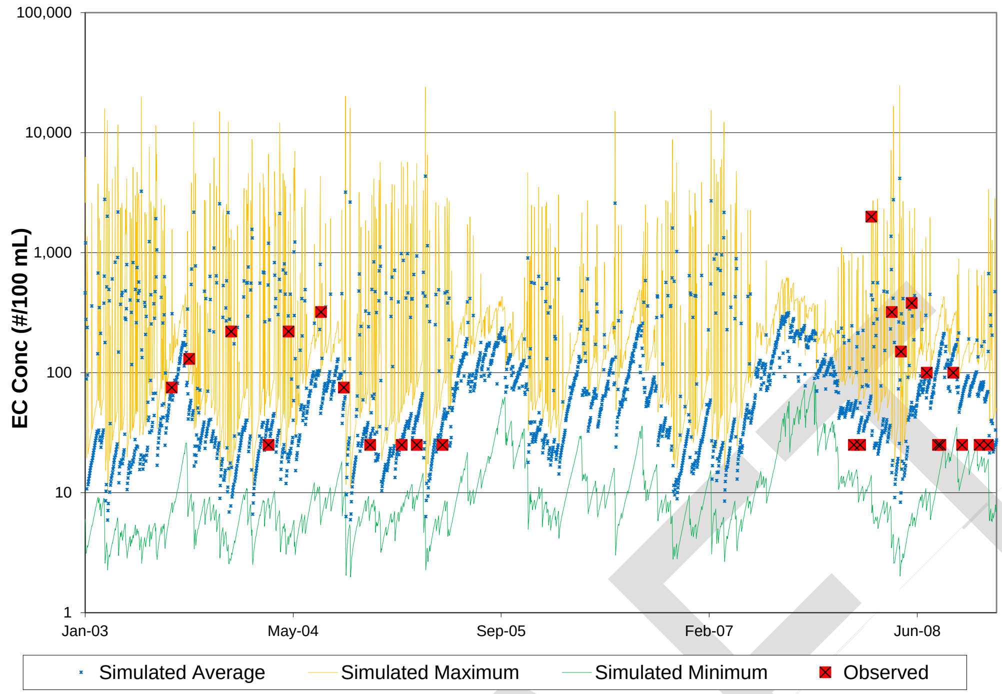


Figure C.14. Observed E. coli data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Stephens Run at station 1BSTV000.20 for the validation period (January 1, 2003 – December 31, 2008).

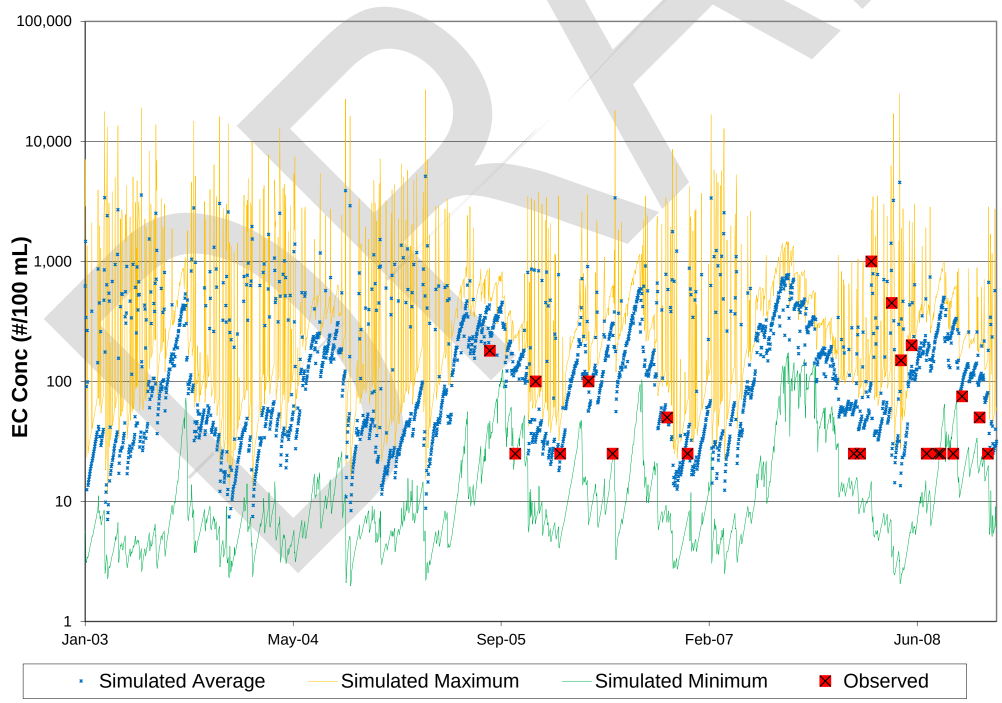


Figure C.15. Observed E. coli data plotted with the daily maximum, minimum, and average simulated fecal coliform values for West Run at station 1BWST000.20 for the validation period (January 1, 2003 – December 31, 2008).

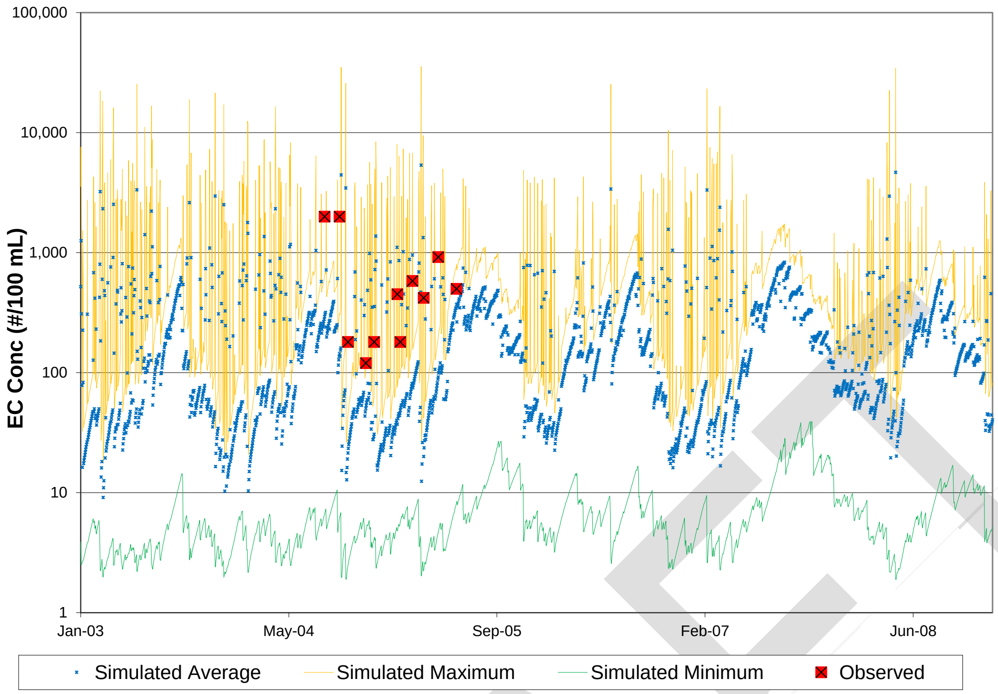


Figure C.16. Observed E. coli data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Willow Brook at station 1BWLO000.71 for the validation period (January 1, 2003 – December 31, 2008).

Table C.7 Calibrated bacteria water quality parameters for the Shenandoah River tributaries watersheds.

Parameter	Definition	Units	FINAL CALIBRATION	FUNCTION OF…
PQUAL				
SQO	Initial storage of constituent	#/ac	0	Land use
POTFW	Washoff potency factor	#/ton	0	
POTFS	Scour potency factor	#/ton	0	
ACQOP	Rate of accumulation of constituent	#/day	Monthly[a]	Land use
SQOLIM	Maximum accumulation of constituent	#	9 x ACQOP[a]	Land use
WSQOP	Wash-off rate	in/hr	0.05 – 0.15	Land use
IOQC	Constituent conc. in interflow	#/ft^3	531	
AOQC	Constituent conc. in active groundwater	#/ft^3	354	
IQUAL				
SQO	Initial storage of constituent	#/ac	$1x10^7$	
POTFW	Washoff potency factor	#/ton	0	
ACQOP	Rate of accumulation of constituent	#/day	$1x10^7$	Land use
SQOLIM	Maximum accumulation of constituent	#	$3x10^7$	Land use
WSQOP	Wash-off rate	in/hr	2.0	Land use
GQUAL				
FSTDEC	First order decay rate of the constituent	1/day	1.15	
THFST	Temperature correction coeff. for FSTDEC		1.05	

[a]Values varied by month and with land use (available on request)

Appendix D: Detailed Land Use Distributions used in Sediment TMDL Development

Table D.1. Modeled Land Use Distributions for Existing Conditions in Happy Creek.

Modeled Land Use/Source Categories	Existing							
	Lower Happy Creek	Leach Run	Middle Happy Creek-1	Middle Happy Creek-2	Middle Happy Creek-3	Sloan Creek	Upper Happy Creek	Happy Creek Total
	Area in acres							
HiTill Rowcrop (hit)	0.0	2.2	0.0	0.0	3.0	10.3	3.8	19.3
LoTill Rowcrop (lot)	0.0	5.1	0.0	0.0	6.9	24.0	8.9	45.0
Pasture (pas_g)	5.0	66.2	1.6	1.8	14.4	54.4	48.4	191.8
Pasture (pas_f)	5.0	66.2	1.6	1.8	14.4	54.4	48.4	191.8
Pasture (pas_p)	6.7	88.2	2.1	2.4	19.3	72.5	64.6	255.8
Riparian pasture (trp)	0.1	0.8	0.0	0.0	0.2	0.7	0.6	2.4
AFO (afo)	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.3
Hay (hay)	25.2	332.3	7.9	9.1	72.5	272.9	243.2	963.2
Forest (for)	191.0	2,022.2	25.7	25.0	552.1	1,563.3	4,903.3	9,282.6
Harvested forest (hvf)	1.9	20.4	0.3	0.3	5.6	15.8	49.5	93.8
Transitional (barren)	0.2	5.3	1.8	6.5	1.0	0.9	0.4	16.1
Pervious LDI (pur_LDI)	32.1	756.7	135.8	432.1	188.1	455.8	300.6	2,301.1
Pervious MDI (pur_MDI)	0.5	36.9	27.2	91.4	11.0	2.2	3.7	172.8
Pervious HDI (pur_HDI)	0.0	0.8	3.1	23.3	1.4	0.0	0.0	28.6
Pervious TRN (pur_rds)	0.0	0.0	5.1	16.0	9.0	17.0	0.0	47.1
Impervious LDI (imp_LDI)	3.3	90.5	21.4	66.2	11.3	11.6	6.5	210.9
Impervious MDI (imp_MDI)	0.5	36.9	27.2	91.4	11.0	2.2	3.7	172.8
Impervious HDI (imp_HDI)	0.0	3.2	12.2	93.4	5.5	0.0	0.2	114.5
Impervious TRN (imp_rds)	0.0	0.0	2.5	8.0	4.5	8.5	0.0	23.6
Total Simulated Area	**271.3**	**3,534.1**	**275.5**	**868.7**	**931.4**	**2,566.5**	**5,686.0**	**14,133.6**
Water	0.4	3.1			1.8	2	3.8	11.1
Total Area	**271.7**	**3,537.2**	**275.5**	**868.7**	**933.2**	**2,568.5**	**5,689.8**	**14,144.7**

Table D.2. Modeled Land Use Distributions for Future Conditions in Happy Creek.

Modeled Land Use/Source Categories	Future							
	Lower Happy Creek	**Leach Run**	**Middle Happy Creek-1**	**Middle Happy Creek-2**	**Middle Happy Creek-3**	**Sloan Creek**	**Upper Happy Creek**	**Happy Creek Total**
	Area in acres							
HiTill Rowcrop (hit)	0.0	1.8	0.0	0.0	3.0	10.3	3.8	18.9
LoTill Rowcrop (lot)	0.0	4.3	0.0	0.0	6.9	24.0	8.9	44.1
Pasture (pas_g)	5.0	58.0	1.6	1.8	14.4	54.4	48.4	183.6
Pasture (pas_f)	5.0	58.0	1.6	1.8	14.4	54.4	48.4	183.6
Pasture (pas_p)	6.7	77.3	2.1	2.4	19.2	72.5	64.6	244.8
Riparian pasture (trp)	0.1	0.7	0.0	0.0	0.2	0.7	0.6	2.3
AFO (afo)	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.3
Hay (hay)	25.2	291.0	7.9	9.1	72.5	272.9	243.2	921.8
Forest (for)	191.0	1,916.2	25.7	25.0	552.1	1,563.3	4,903.3	9,176.6
Harvested forest (hvf)	1.9	19.4	0.3	0.3	5.6	15.8	49.5	92.7
Transitional (barren)	0.2	7.2	1.8	6.5	1.1	0.9	0.4	18.2
Pervious LDI (pur_LDI)	32.1	881.2	135.8	429.8	172.2	455.8	300.6	2,407.4
Pervious MDI (pur_MDI)	0.5	39.4	27.2	89.5	7.5	2.2	3.7	169.9
Pervious HDI (pur_HDI)	0.0	3.0	3.1	24.7	6.2	0.0	0.0	36.9
Pervious TRN (pur_rds)	0.0	0.0	5.1	16.0	9.0	17.0	0.0	47.1
Impervious LDI (imp_LDI)	3.3	125.3	21.4	65.7	10.3	11.6	6.5	244.1
Impervious MDI (imp_MDI)	0.5	39.4	27.2	89.5	7.5	2.2	3.7	169.9
Impervious HDI (imp_HDI)	0.0	11.9	12.2	98.7	24.8	0.0	0.2	147.7
Impervious TRN (imp_rds)	0.0	0.0	2.5	8.0	4.5	8.5	0.0	23.6
Total Simulated Area	**271.3**	**3,534.1**	**275.5**	**868.7**	**931.4**	**2,566.5**	**5,686.0**	**14,133.6**
Water	0.4	3.1			1.8	2	3.8	11.1
Total Area	**271.7**	**3,537.2**	**275.5**	**868.7**	**933.2**	**2,568.5**	**5,689.8**	**14,144.7**

Table D.3. Modeled Land Use Distributions for Existing Conditions in AllForX Comparison Watersheds for Happy Creek.

Modeled Land Use/Source Categories	AllForX Comparison Watersheds									
	Beaverdam Creek	Fiery Run	Hawksbill Creek	Hogue Creek	Hughes River	Mill Creek	NF Catoctin Creek	Rose River	Thumb Run	Manassas Run
	Area in acres									
HiTill Rowcrop (hit)	431.0	6.6	669.6	71.6	200.3	24.2	129.9	0.0	121.1	5.1
LoTill Rowcrop (lot)	1,005.6	15.4	1,562.5	167.1	467.3	56.5	303.0	0.0	282.6	11.9
Pasture (pas_g)	1,981.2	91.5	1,780.5	352.0	769.2	304.8	365.9	0.0	886.2	59.4
Pasture (pas_f)	1,981.2	91.5	1,780.5	352.0	769.2	304.8	365.9	0.0	886.2	59.4
Pasture (pas_p)	2,641.6	122.0	2,374.0	469.3	1,025.6	406.5	487.9	0.0	1,181.6	79.2
Riparian pasture (trp)	24.8	1.1	22.3	4.4	9.6	3.8	4.6	0.0	11.1	0.7
AFO (afo)	2.9	0.1	2.6	0.5	1.1	0.5	0.5	0.0	1.3	0.1
Hay (hay)	9,947.5	459.2	8,939.9	1,767.3	3,862.3	1,530.6	1,837.3	0.0	4,449.8	298.1
Forest (for)	10,902.1	4,995.1	33,053.2	13,639.4	22,437.4	12,042.4	4,564.8	0.0	8,354.8	5,375.1
Harvested forest (hvf)	110.1	50.5	333.9	137.8	226.6	121.6	46.1	0.0	84.4	54.3
Transitional (barren)	1.3	0.0	21.3	3.8	0.2	0.7	0.4	0.0	0.1	2.2
Pervious LDI (pur_LDI)	1,496.1	82.2	5,672.9	1,936.7	882.0	678.4	388.8	0.0	591.0	1,038.5
Pervious MDI (pur_MDI)	4.9	0.0	137.1	24.5	0.5	3.7	1.1	0.0	0.0	4.4
Pervious HDI (pur_HDI)	0.0	0.0	14.3	0.7	0.0	0.0	0.0	0.0	0.0	0.2
Pervious TRN (pur_rds)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Impervious LDI (imp_LDI)	24.6	0.1	357.0	65.9	3.1	12.0	7.5	0.0	1.6	42.6
Impervious MDI (imp_MDI)	4.9	0.0	137.1	24.5	0.5	3.7	1.1	0.0	0.0	4.4
Impervious HDI (imp_HDI)	0.2	0.0	57.0	2.8	0.0	0.2	0.0	0.0	0.0	0.7
Impervious TRN (imp_rds)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Simulated Area	**30,560.0**	**5,915.3**	**56,915.7**	**19,020.3**	**30,655.1**	**15,494.3**	**8,504.9**	**0.0**	**16,851.9**	**7,036.2**
Water	77.6	9.7	49.6	56.6	38.7	6.4	24.5	0.2	40.5	4.0
Total Area	**30,637.6**	**5,925.0**	**56,965.3**	**19,076.9**	**30,693.8**	**15,500.8**	**8,529.3**	**0.2**	**16,892.4**	**7,040.2**

Appendix E: Detailed Simulated Sediment Loads

Table E.1. Simulated Sediment Loads for Existing Conditions in Happy Creek Watershed.

	HPY1	HPY2	HPY3	HPY4	HPY5	HPY6	HPY7		
Land Use/Source Categories	**Lower Happy Creek**	**Leach Run**	**Middle Happy Creek-1**	**Middle Happy Creek-2**	**Middle Happy Creek-3**	**Sloan Creek**	**Upper Happy Creek**	**Happy Creek Total**	**Unit-Area Load**
	Sediment Load (tons/yr)								**(tons/ac)**
HiTill Rowcrop (hit)	0.0	11.3	0.0	0.0	20.9	80.4	23.5	136.1	7.06
LoTill Rowcrop (lot)	0.0	6.2	0.0	0.0	11.3	44.7	13.1	75.3	1.67
Pasture (pas_g)	0.4	10.4	0.0	0.4	5.6	17.5	13.8	48.0	0.25
Pasture (pas_f)	1.9	47.7	0.2	1.9	25.3	79.1	62.5	218.5	1.14
Pasture (pas_p)	5.3	134.4	0.5	5.4	71.2	212.9	166.1	595.7	2.33
Riparian pasture (trp)	0.5	10.9	0.0	0.4	5.5	16.6	13.1	47.0	19.60
AFO (afo)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
Hay (hay)	6.3	162.8	0.6	6.4	85.9	264.2	208.9	735.1	0.76
Forest (for)	7.6	82.9	0.7	0.8	35.9	83.4	348.6	559.8	0.06
Harvested forest (hvf)	0.6	6.6	0.1	0.1	2.8	6.4	26.4	43.0	0.46
Transitional (barren)	2.6	46.1	13.8	47.3	22.1	6.9	4.9	143.8	8.90
Pervious LDI (pur_LDI)	8.4	141.0	19.9	83.6	52.8	140.5	83.0	529.1	0.23
Pervious MDI (pur_MDI)	0.0	3.6	3.0	5.0	1.2	0.4	0.8	14.1	0.08
Pervious HDI (pur_HDI)	0.0	0.0	0.3	0.7	0.0	0.0	0.0	1.1	0.04
Pervious TRN (pur_rds)	0.0	0.0	0.4	0.8	3.2	5.5	0.0	9.9	0.21
Impervious LDI (imp_LDI)	0.3	6.4	1.8	5.4	1.0	0.9	0.5	16.2	0.08
Impervious MDI (imp_MDI)	0.2	12.2	10.9	36.2	4.2	0.7	1.3	65.7	0.38
Impervious HDI (imp_HDI)	0.0	0.7	3.1	23.3	1.3	0.0	0.0	28.4	0.25
Impervious TRN (imp_rds)	0.0	0.0	0.5	1.4	0.8	1.2	0.0	3.9	0.17
Channel Erosion	15.6	1.8	4.3	12.8	8.0	1.3	3.9	47.6	
Point Sources	0.0	0.4	3.1	0.3	0.1	0.0	0.0	3.9	
Total Sediment Load	**49.6**	**685.2**	**63.0**	**232.0**	**359.1**	**962.8**	**970.6**	**3,322.3**	

Table E.2. Simulated Sediment Loads for Future Conditions in Happy Creek Watershed.

	HPY1	HPY2f	HPY3	HPY4f	HPY5f	HPY6	HPY7		
Land Use/Source Categories	**Lower Happy Creek**	**Leach Run**	**Middle Happy Creek-1**	**Middle Happy Creek-2**	**Middle Happy Creek-3**	**Sloan Creek**	**Upper Happy Creek**	**Happy Creek Total**	**Unit-Area Load**
	Sediment Load (tons/yr)								**(tons/ac)**
HiTill Rowcrop (hit)	0.0	9.5	0.0	0.0	20.8	80.4	23.5	134.3	6.97
LoTill Rowcrop (lot)	0.0	5.2	0.0	0.0	11.3	44.7	13.1	74.3	1.65
Pasture (pas_g)	0.4	9.1	0.0	0.4	5.6	17.5	13.8	46.7	0.24
Pasture (pas_f)	1.9	41.7	0.2	1.9	25.2	79.1	62.5	212.5	1.11
Pasture (pas_p)	5.3	117.6	0.5	5.4	71.0	212.9	166.1	578.7	2.26
Riparian pasture (trp)	0.5	9.5	0.0	0.4	5.5	16.6	13.1	45.6	19.02
AFO (afo)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
Hay (hay)	6.3	142.4	0.6	6.4	85.6	264.2	208.9	714.4	0.74
Forest (for)	7.6	78.4	0.7	0.8	35.8	83.4	348.6	555.3	0.06
Harvested forest (hvf)	0.6	6.2	0.1	0.1	2.8	6.4	26.4	42.6	0.45
Transitional (barren)	2.6	62.4	13.8	47.4	24.6	6.9	4.9	162.7	10.08
Pervious LDI (pur_LDI)	8.4	164.0	19.9	83.1	48.2	140.5	83.0	547.0	0.24
Pervious MDI (pur_MDI)	0.0	3.9	3.0	4.9	0.8	0.4	0.8	13.9	0.08
Pervious HDI (pur_HDI)	0.0	0.2	0.3	0.7	0.2	0.0	0.0	1.4	0.05
Pervious TRN (pur_rds)	0.0	0.0	0.4	0.8	3.2	5.5	0.0	9.9	0.21
Impervious LDI (imp_LDI)	0.3	8.9	1.8	5.3	0.9	0.9	0.5	18.5	0.09
Impervious MDI (imp_MDI)	0.2	13.0	10.9	35.4	2.9	0.7	1.3	64.4	0.37
Impervious HDI (imp_HDI)	0.0	2.5	3.1	24.6	6.0	0.0	0.0	36.2	0.32
Impervious TRN (imp_rds)	0.0	0.0	0.5	1.4	0.8	1.2	0.0	3.9	0.17
Channel Erosion	17.3	2.1	4.4	12.9	8.4	1.3	3.9	50.2	
Point Sources	0.0	0.4	3.1	0.3	0.1	0.0	0.0	3.9	
Total Sediment Load	**51.4**	**676.8**	**63.1**	**232.2**	**359.8**	**962.8**	**970.6**	**3,316.6**	

Table E.3. Simulated Sediment Loads for Existing Conditions in Cumulative Watersheds at Happy Creek Biological Monitoring Stations and AllForX Comparison Watersheds.

Land Use/Source Categories	TMDL Watersheds		AllForX Comparison Watersheds									
	Middle Happy Creek-1	**Middle Happy Creek-2**	**Beaverdam Creek**	**Fiery Run**	**Hawksbill Creek**	**Hogue Creek**	**Hughes River**	**Mill Creek**	**NF Catoctin Creek**	**Rose River**	**Thumb Run**	**Manassas Run**
	HPY3x	**HPY4x**	**BEC**	**FIR**	**HKS**	**HOC**	**HUE**	**MIL**	**NOC**	**ROE**	**THU**	**MAN**
	Sediment Load in metric tons/yr											
HiTill Rowcrop (hit)	124.1	125.0	1,093.4	39.7	459.2	99.7	519.8	38.3	429.2	18.0	321.0	0.0
LoTill Rowcrop (lot)	68.7	69.3	524.5	18.9	250.3	55.2	245.2	21.1	236.2	8.7	152.2	20.1
Pasture (pas_g)	37.0	37.3	149.9	20.1	89.5	31.1	88.4	26.5	39.6	6.0	108.4	16.5
Pasture (pas_f)	168.0	169.0	746.0	90.6	424.4	138.5	428.1	127.1	201.9	28.5	497.0	72.9
Pasture (pas_p)	453.3	456.2	2,180.9	246.5	1,237.1	376.2	1,343.8	345.9	649.7	85.1	1,413.9	202.1
Riparian pasture (trp)	35.5	35.7	176.3	19.9	100.4	30.5	109.0	0.3	52.7	6.9	114.7	12.0
AFO (afo)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hay (hay)	562.5	566.1	2,592.6	301.3	1,459.1	470.0	1,544.8	415.3	720.8	101.6	1,694.1	246.3
Forest (for)	466.5	469.2	209.8	298.0	1,040.4	331.1	765.8	263.1	116.5	294.0	303.6	330.3
Harvested forest (hvf)	35.6	35.8	17.8	23.2	81.3	25.6	62.1	21.6	10.8	24.5	24.6	25.5
Transitional (barren)	94.6	81.4	9.1	0.1	51.0	8.5	0.9	1.3	2.6	1.3	0.7	36.2
Pervious LDI (pur_LDI)	377.4	360.3	168.0	19.0	416.0	250.0	124.2	81.5	51.1	64.0	61.0	0.0
Pervious MDI (pur_MDI)	10.4	7.5	0.7	0.0	6.4	2.6	0.0	0.2	0.1	0.3	0.0	0.0
Pervious HDI (pur_HDI)	1.0	0.8	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pervious TRN (pur_rds)	9.8	9.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Impervious LDI (imp_LDI)	9.4	7.7	2.2	0.0	30.2	6.5	0.3	1.1	0.6	0.6	0.1	0.0
Impervious MDI (imp_MDI)	53.0	42.5	2.0	0.0	57.5	10.1	0.2	1.5	0.5	1.4	0.0	0.0
Impervious HDI (imp_HDI)	27.5	24.7	0.0	0.0	15.0	0.7	0.0	0.0	0.0	0.1	0.0	0.0
Impervious TRN (imp_rds)	3.9	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Channel Erosion	27.4	23.5	186.8	6.0	260.7	27.0	67.8	14.3	4.2	0.0	42.1	8.5
Point Sources	3.2	0.4										
Existing Sediment Load	**2,568.9**	**2,525.3**	**8,060.2**	**1,083.3**	**5,979.0**	**1,863.2**	**5,300.3**	**1,359.2**	**2,516.5**	**641.0**	**4,733.5**	**970.2**
All-Forested Sediment Load	**591.2**	**583.8**	**567.1**	**334.3**	**1,351.4**	**427.5**	**950.7**	**319.6**	**177.2**	**311.1**	**486.4**	**354.6**
AllForX*	**4.3**	**4.3**	**14.2**	**3.2**	**4.4**	**4.4**	**5.6**	**4.3**	**14.2**	**2.1**	**9.7**	**2.7**

Appendix F: GWLF Model Parameters

The GWLF parameter values used for the Happy Creek watershed simulations are shown in Table F.1 through Table F.3. Table F.1 lists the various watershed-wide parameters and their values, Table F.2 displays the monthly variable evapo-transpiration cover coefficients, and Table F.3 shows the land use-related parameters – runoff curve numbers (CN) and the Universal Soil Loss Equation's KLSCP product - used for erosion modeling. Corresponding GWLF parameter values for the AllForX comparison watersheds are shown in Table F.4 through Table F.6. Since the modeling was performed in metric units, note that all of the input parameters are in metric units, even though the simulated results shown in this report are presented in English units.

Table F.1. GWLF Watershed Parameters for Happy Creek.

GWLF Watershed Parameters	units	Happy Creek						
		HPY1	HPY2	HPY3	HPY4	HPY5	HPY6	HPY7
recession coefficient	(day^{-1})	0.8498	0.1224	0.8403	0.3407	0.3223	0.1507	0.0935
seepage coefficient		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
leakage coefficient		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
sediment delivery ratio		0.1965	0.1790	0.1964	0.1931	0.1928	0.1840	0.1684
unsaturated water capacity	(cm)	16.25	14.57	16.38	16.81	14.98	14.95	14.83
erosivity coefficient (Nov - Apr)		0.138	0.138	0.138	0.138	0.138	0.138	0.138
erosivity coefficient (growing season)		0.264	0.264	0.264	0.264	0.264	0.264	0.264
% developed land	(%)	1.6	4.8	35.9	35.9	5.8	1.6	0.2
no. of livestock	(AU)	3	45	1	1	10	37	33
area-weighted runoff curve number		63.90	67.13	74.28	74.28	67.95	70.61	69.19
area-weighted soil erodibility		0.349	0.313	0.301	0.301	0.290	0.321	0.337
area-weighted slope	(%)	9.32	13.82	6.40	6.40	19.17	18.33	23.77
aFactor		0.0000862	0.0001258	0.0005762	0.0005762	0.0001369	0.0000913	0.0000806
total stream length	(m)	985.6	4,543.6	1,086.2	1,086.2	3,441.6	6,358.0	10,403.0
Mean Channel Depth	(m)	0.242	0.558	0.243	0.243	0.362	0.503	0.651

Table F.2. GWLF Monthly ET Cover Coefficients – Happy Creek.

Watershed	ID	Apr	May	Jun	Jul*	Aug	Sep	Oct	Nov	Dec	Jan**	Feb	Mar
Lower Happy Creek	HPY1	0.975	0.983	0.986	**0.986**	0.959	0.932	0.905	0.851	0.824	**0.806**	0.896	0.957
Leach Run	HPY2	0.953	0.960	0.962	**0.962**	0.939	0.916	0.892	0.846	0.823	**0.808**	0.885	0.937
Middle Happy Creek-1	HPY3	0.763	0.765	0.765	**0.765**	0.761	0.756	0.751	0.742	0.738	**0.735**	0.750	0.760
Middle Happy Creek-2	HPY4	0.696	0.696	0.697	**0.697**	0.695	0.694	0.692	0.689	0.688	**0.687**	0.692	0.695
Middle Happy Creek-3	HPY5	0.955	0.962	0.964	**0.964**	0.941	0.918	0.894	0.847	0.824	**0.808**	0.886	0.939
Sloan Creek	HPY6	0.981	0.988	0.991	**0.991**	0.965	0.939	0.913	0.862	0.836	**0.819**	0.905	0.963
Upper Happy Creek	HPY7	0.987	0.995	0.998	**0.998**	0.969	0.940	0.911	0.854	0.825	**0.806**	0.902	0.967

* July values represent the maximum composite ET coefficients during the growing season.

** Jan values represent the minimum composite ET coefficients during the dormant season.

Table F.3. GWLF Land Use Parameters – Happy Creek.

Landuse	Lower Happy Creek (HPY1)		Leach Run (HPY2)		Middle Happy Creek-1 (HPY3)		Middle Happy Creek-		Middle Happy Creek-3 (HPY5)		Sloan Creek (HPY6)		Upper Happy Creek (HPY7)	
	KLSCP	CN	KLSCP	CN	KLSCP	CN	KLSCP	CN	KLSCP	CN	KLSCP	CN	KLSCP	CN
HiTill Rowcrop (hit)	0.5412	79.7	0.6704	80.8	0.3079	79.2	0.3055	78.8	0.7181	81.4	0.9910	83.3	0.7832	83.7
LoTill Rowcrop (lot)	0.1315	77.8	0.1629	78.9	0.0748	77.3	0.0742	76.9	0.1745	79.4	0.2407	81.4	0.1903	81.7
Pasture (pas_g)	0.0103	61.9	0.0281	63.7	0.0034	61.0	0.0333	60.2	0.0538	64.8	0.0527	68.5	0.0460	69.2
Pasture (pas_f)	0.0410	69.7	0.1125	71.0	0.0136	69.0	0.1333	68.3	0.2153	71.8	0.2108	74.7	0.1839	75.3
Pasture (pas_p)	0.0728	79.5	0.1997	80.5	0.0241	79.0	0.2366	78.6	0.3821	81.1	0.3742	83.0	0.3265	83.4
Riparian pasture (trp)	0.6879	79.5	1.7188	80.5	0.1948	79.0	2.0349	78.6	3.1593	81.1	3.1086	83.0	2.7318	83.4
AFO (afo)	0.0000	91.0	0.0000	91.0	0.0000	91.0	0.0000	91.0	0.0000	91.0	0.0000	91.0	0.0000	91.0
Hay (hay)	0.0277	69.7	0.0759	71.1	0.0092	69.0	0.0900	68.5	0.1453	71.7	0.1423	74.2	0.1242	74.7
Forest (for)	0.0053	60.9	0.0075	62.6	0.0043	60.0	0.0048	59.1	0.0092	63.7	0.0089	67.5	0.0116	68.2
Harvested forest (hvf)	0.0528	66.8	0.0753	68.3	0.0435	66.0	0.0483	65.2	0.0922	69.1	0.0891	72.3	0.1156	72.9
Transitional (barren)	1.5593	86.4	1.3350	87.1	0.8872	86.0	0.8804	85.7	2.7135	87.4	1.2013	88.9	1.8513	89.2
Pervious LDI (pur_LDI)	0.0290	69.7	0.0294	71.0	0.0183	69.0	0.0251	68.3	0.0348	71.8	0.0451	74.7	0.0398	75.3
Pervious MDI (pur_MDI)	0.0071	69.7	0.0156	71.0	0.0138	69.0	0.0071	68.3	0.0141	71.8	0.0281	74.7	0.0311	75.3
Pervious HDI (pur_HDI)	0.0306	69.7	0.0084	71.0	0.0117	69.0	0.0039	68.3	0.0038	71.8	0.0567	74.7	0.0477	75.3
Pervious Roads (pur_rds)	0.0306	69.7	0.0415	71.0	0.0093	69.0	0.0061	68.3	0.0442	71.8	0.0476	74.7	0.0736	75.3
Impervious LDI (imp_LDI)	0.0000	89.2	0.0000	89.5	0.0000	89.0	0.0000	88.8	0.0000	89.8	0.0000	90.7	0.0000	90.9
Impervious MDI (imp_MDI)	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0
Impervious HDI (imp_HDI)	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0
Impervious Roads (imp_rds)	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0

LDI = low intensity developed; MDI = medium intensity developed; HDI = high intensity developed

Table F.4. GWLF Watershed Parameters for AllForX Comparison Watersheds.

GWLF Watershed Parameters	units	AllForX Comparison Watersheds									
		BEC	FIR	HKS	HOC	HUE	MIL	NOC	ROE	THU	MAN
recession coefficient	(day^{-1})	0.0541	0.0916	0.0499	0.0596	0.0541	0.0629	0.0775	0.0728	0.0615	0.0843
seepage coefficient		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
leakage coefficient		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
sediment delivery ratio		0.1075	0.1674	0.0893	0.1238	0.1074	0.1316	0.1557	0.1497	0.1284	0.1622
unsaturated water capacity	(cm)	16.31	17.16	14.67	14.98	13.90	13.52	14.59	5.88	16.61	14.70
erosivity coefficient (Nov - Apr)		0.080	0.138	0.119	0.097	0.116	0.191	0.080	0.083	0.138	0.138
erosivity coefficient (growing season)		0.172	0.264	0.205	0.276	0.197	0.228	0.172	0.176	0.264	0.264
% developed land	(%)	0.1	0.0	1.2	0.6	0.0	0.1	0.1	0.1	0.0	0.0
no. of livestock	(AU)	1,344	62	1,207	239	522	207	248	26	601	601
area-weighted runoff curve number		65.76	68.01	60.75	73.06	50.71	73.06	60.40	50.69	66.55	66.55
area-weighted soil erodibility		0.328	0.305	0.268	0.250	0.264	0.252	0.271	0.117	0.316	0.316
area-weighted slope	(%)	7.44	19.39	18.74	14.78	22.51	18.62	11.32	29.03	13.21	13.21
aFactor		0.0000605	0.0000586	0.0000544	0.0000449	0.0000282	0.0000425	0.0000328	0.0000001	0.0000594	0.0000594
total stream length	(m)	84,846.1	16,379.7	116,809.8	52,227.7	86,068.6	45,203.2	16,346.3	21,820.3	42,389.6	42,389.6
Mean Channel Depth	(m)	1.522	0.929	1.376	0.811	1.125	0.764	0.742	0.781	1.273	1.273

Table F.5. GWLF Monthly ET Cover Coefficients – AllForX Comparison Watersheds

Watershed	ID	Apr	May	Jun	Jul*	Aug	Sep	Oct	Nov	Dec	Jan**	Feb	Mar
Beaverdam Creek	BEC	0.985	0.995	0.999	**0.999**	0.965	0.931	0.897	0.829	0.795	**0.773**	0.886	0.962
Fiery Run	FIR	0.988	0.997	1.000	**1.000**	0.969	0.939	0.908	0.847	0.817	**0.796**	0.898	0.967
Hawksbill Creek	HKS	0.978	0.987	0.990	**0.990**	0.960	0.930	0.900	0.840	0.810	**0.790**	0.890	0.958
Hogue Creek	HOC	0.984	0.992	0.995	**0.995**	0.967	0.938	0.910	0.854	0.825	**0.807**	0.901	0.965
Hughes River	HUE	0.987	0.997	1.000	**1.000**	0.968	0.937	0.906	0.843	0.812	**0.791**	0.895	0.966
Mill Creek	MIL	0.987	0.996	0.999	**0.999**	0.969	0.939	0.909	0.849	0.820	**0.800**	0.899	0.967
NF Catoctin Creek	NOC	0.985	0.995	0.999	**0.999**	0.966	0.933	0.900	0.834	0.801	**0.778**	0.889	0.963
Rose River	ROE	0.987	0.996	0.999	**0.999**	0.970	0.941	0.912	0.854	0.825	**0.806**	0.902	0.968
Thumb Run	THU	0.986	0.996	1.000	**1.000**	0.967	0.934	0.902	0.836	0.804	**0.782**	0.891	0.965
Manassas Run	MAN	0.988	0.997	1.000	**1.000**	0.970	0.940	0.910	0.850	0.820	**0.800**	0.900	0.968

* July values represent the maximum composite ET coefficients during the growing season.

** Jan values represent the minimum composite ET coefficients during the dormant season.

Table F.6. GWLF Land Use Parameters – AllForX Comparison Watersheds.

Landuse	Beaverdam Creek (BEC)		Fiery Run (FIR)		Hawksbill Creek (HKS)		Hogue Creek (HOC)		Hughes River (HUE)		Mill Creek (MIL)		NF Catoctin Creek (NOC)		Rose River (ROE)		Thumb Run (THU)		Manassas Run (MAN)	
	KLSCP	CN	KLSCP	CN	KLSCP	CN	KLSCP	CN	KLSCP	CN	KLSCP	CN	KLSCP	CN	KLSCP	CN	KLSCP	CN	KLSCP	CN
HiTill Rowcrop (hit)	0.3754	78.6	0.6817	82.4	0.1406	77.6	0.2523	85.6	0.3966	73.1	0.3600	85.6	0.3391	77.1	0.3199	74.3	0.4069	79.8	0.8291	83.1
LoTill Rowcrop (lot)	0.0793	76.2	0.1440	80.1	0.0342	75.6	0.0613	83.5	0.0838	70.7	0.0875	83.6	0.0824	75.2	0.0676	72.0	0.0859	77.5	0.2014	81.1
Pasture (pas_g)	0.0173	60.1	0.0323	67.9	0.0152	57.1	0.0207	72.2	0.0283	49.0	0.0274	72.6	0.0195	56.1	0.0196	51.7	0.0259	62.9	0.0420	67.8
Pasture (pas_f)	0.0693	67.6	0.1292	74.2	0.0609	65.2	0.0826	77.6	0.1133	57.8	0.1097	77.9	0.0782	64.4	0.0784	60.3	0.1034	70.1	0.1679	74.1
Pasture (pas_p)	0.1229	78.7	0.2293	82.7	0.1081	77.1	0.1467	84.9	0.2011	73.1	0.1948	85.3	0.1388	76.6	0.1392	74.4	0.1836	80.1	0.2980	82.7
Riparian pasture (trp)	1.0530	78.7	1.9645	82.7	0.9278	77.1	1.2637	84.9	1.7311	73.1	1.6750	85.3	1.1942	76.6	1.1997	74.4	1.5814	80.1	2.5300	82.7
AFO (afo)	0.0000	91.0	0.0000	91.0	0.0000	91.0	0.0000	91.0	0.0000	91.0	0.0000	91.0	0.0000	91.0	0.0000	91.0	0.0000	91.0	0.0000	91.0
Hay (hay)	0.0468	68.9	0.0872	73.9	0.0411	66.6	0.0558	77.4	0.0765	61.6	0.0741	77.0	0.0528	66.0	0.0529	63.2	0.0698	70.5	0.1133	73.9
Forest (for)	0.0046	58.6	0.0089	66.8	0.0095	55.6	0.0058	71.0	0.0087	46.7	0.0071	71.6	0.0051	54.5	0.0042	49.7	0.0080	61.7	0.0095	66.7
Harvested forest (hvf)	0.0462	64.9	0.0893	71.8	0.0951	62.1	0.0581	75.8	0.0868	54.4	0.0708	75.8	0.0514	61.2	0.0421	57.0	0.0804	67.4	0.0949	71.7
Transitional (barren)	1.1614	85.7	2.4174	88.7	0.5605	84.4	0.4827	90.7	0.8893	81.1	0.5313	90.5	0.7928	84.0	0.3818	82.2	1.1204	86.7	2.2584	88.6
Pervious LDI (pur_LDI)	0.0212	67.6	0.0302	74.2	0.0186	65.2	0.0274	77.6	0.0286	57.8	0.0317	77.9	0.0191	64.4	0.0165	60.3	0.0191	70.1	0.0493	74.1
Pervious MDI (pur_MDI)	0.0288	67.6	0.0157	74.2	0.0119	65.2	0.0223	77.6	0.0138	57.8	0.0117	77.9	0.0171	64.4	0.0091	60.3	0.0164	70.1	0.0163	74.1
Pervious HDI (pur_HDI)	0.0054	67.6	0.0100	74.2	0.0079	65.2	0.0079	77.6	0.0089	57.8	0.0111	77.9	0.0079	64.4	0.0050	60.3	0.0104	70.1	0.0180	74.1
Pervious Roads (pur_rds)	0.0204	67.6	0.0259	74.2	0.0136	65.2	0.0199	77.6	0.0198	57.8	0.0197	77.9	0.0163	64.4	0.0109	60.3	0.0175	70.1	0.0000	74.1
Impervious LDI (imp_LDI)	0.0000	88.5	0.0000	90.5	0.0000	87.9	0.0000	91.3	0.0000	85.6	0.0000	91.7	0.0000	87.6	0.0000	86.4	0.0000	89.3	0.0000	90.5
Impervious MDI (imp_MDI)	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0
Impervious HDI (imp_HDI)	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0
Impervious Roads (imp_rds)	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0

LDI = low intensity developed; MDI = medium intensity developed; HDI = high intensity developed

Appendix G: Setting TMDL Endpoints and MOS using the AllForX Approach

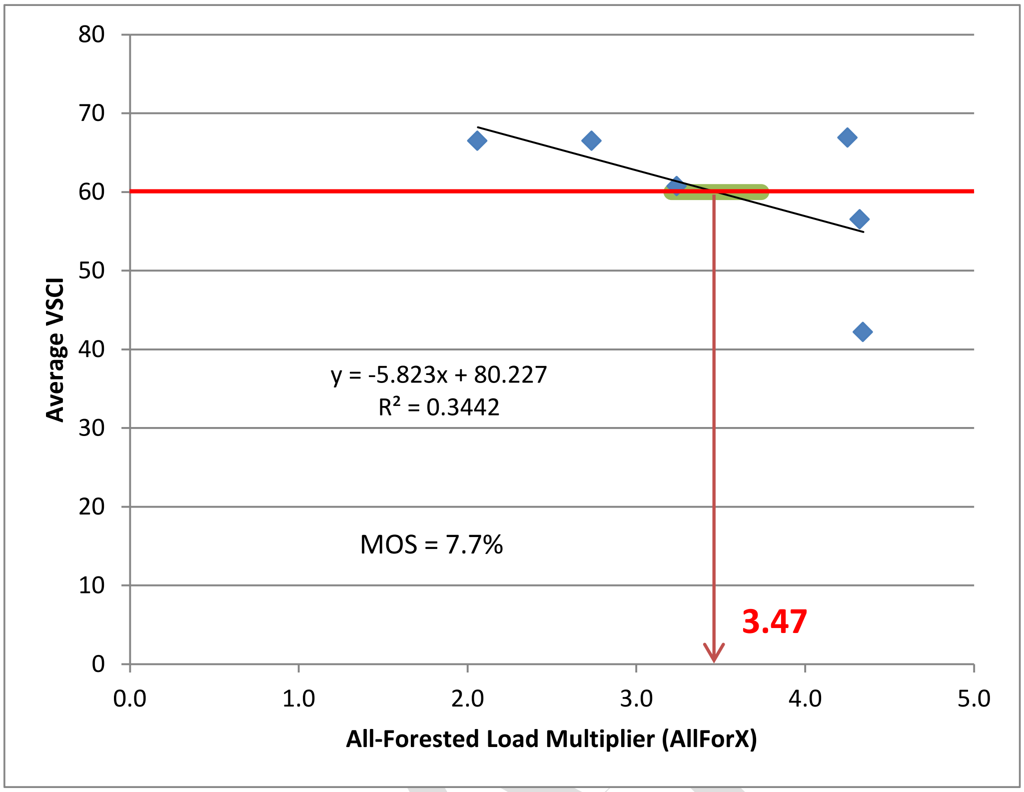
In the AllForX approach, the metric used for setting a numeric sediment threshold is the All-Forest Load Multiplier (AllForX) calculated as the existing sediment load normalized by the corresponding load under an all-forest condition. The AllForX metric is calculated for each watershed. When AllForX is regressed against VSCI for a number of healthy comparison watersheds surrounding a particular TMDL watershed or set of TMDL watersheds, the developed relationship can be used to quantify the value of AllForX for the biological health threshold (VSCI < 60) used to assess aquatic life use impairments in Virginia. The sediment TMDL load is then calculated as the value of AllForX at the VSCI threshold times the all-forest sediment load of the TMDL watershed. Since a number of watersheds are used to quantify the regression, a confidence interval around the threshold was used to quantify the margin of safety in the Total Maximum Daily Load equation.

Existing sediment loads were calculated for each of the TMDL watersheds contributing to the two (2) impaired segments in this study and for each of the four (4) comparison watersheds. A modeling scenario was then created and run, which substituted forest land use-related parameters for each of the other land uses, while preserving the unique characteristics of soil and slope distributions across each watershed. AllForX was then calculated by dividing the existing sediment load by the all-forest load. The modeling results for each watershed are summarized as long-term averages for each watershed in Table G.1.

Table G.1. Metrics used in the AllForX Approach.

Land Use/Source Categories	TMDL Watersheds		AllForX Comparison Watersheds			
	Middle Happy Creek-1	Middle Happy Creek-2	Fiery Run	Mill Creek	Rose River	Manassas Run
	HPY3x	HPY4x	FIR	MIL	ROE	MAN
	Sediment Load in metric tons/yr					
Existing Sediment Load	**2,568.9**	**2,525.3**	**1,083.3**	**1,359.2**	**641.0**	**970.2**
All-Forested Sediment Load	**591.2**	**583.8**	**334.3**	**319.6**	**311.1**	**354.6**
AllForX*	**4.3**	**4.3**	**3.2**	**4.3**	**2.1**	**2.7**
Average VSCI	**42.2**	**56.5**	**60.73**	**66.88**	**66.51**	**66.49**

A regression between AllForX and VSCI was developed using all six (6) watersheds, as shown in Figure G.1. The value of AllForX used to set the sediment TMDL load was the value where the regression line crossed the biological impairment threshold of VSCI = 60 (AllForX = 3.47), indicated by point B. The TMDL load for each watershed was calculated as its All-Forest sediment load times the threshold AllForX value (3.47). An 80% confidence interval was then calculated around the point where the regression line intersects the biological impairment threshold (VSCI = 60). The margin of safety (MOS) was calculated as the All-Forest sediment load times the difference in AllForX between the point where the regression crosses VSCI = 60 (AllForX = 3.47) and the lower bound of the 80% confidence interval (AllForX = 3.21). Note that the MOS is equal to this difference expressed as a percentage of the threshold AllForX, and therefore is the same for all watersheds using this regression. Existing, TMDL, and MOS loads are shown in Table G.2 for the TMDL watershed. Since the MOS is a measure of uncertainty in the TMDL, the implementation target load is the TMDL minus the MOS, and the percent reduction is calculated as the change from the future load to the allocation target load.



B = AllForX value used for the TMDL; AC = the 80% Confidence Interval (shown in green);
B – A = AllForX value used for the MOS; A = AllForX value used for the target allocation load.

Figure G.1. Regression and AllForX Threshold for Sediment in Happy Creek.

Table G.2. Calculation of the TMDL and MOS for Happy Creek.

Calculated Metric	Units	Existing	Future
All-Forest Sediment Load	tons/yr	723.0	
AllForX @ VSCI = 60		3.47	
TMDL Sediment Load	tons/yr	2,511.3	
Margin of Safety (MOS)	tons/yr	192.4	
TMDL Reduction Endpoint (TMDL-MOS)	tons/yr		2,318.8
Overall Reduction from Future Load	tons/yr		997.8
Overall %Reduction from Future Load	%		30.1%

The relationship between AllForX and the biological condition was further validated with the following plots and regressions between AllForX and various independent sediment-related habitat metrics: average habitat sediment deposition in Figure G.2; average embeddedness in Figure G.3; and total habitat score in Figure G.4.

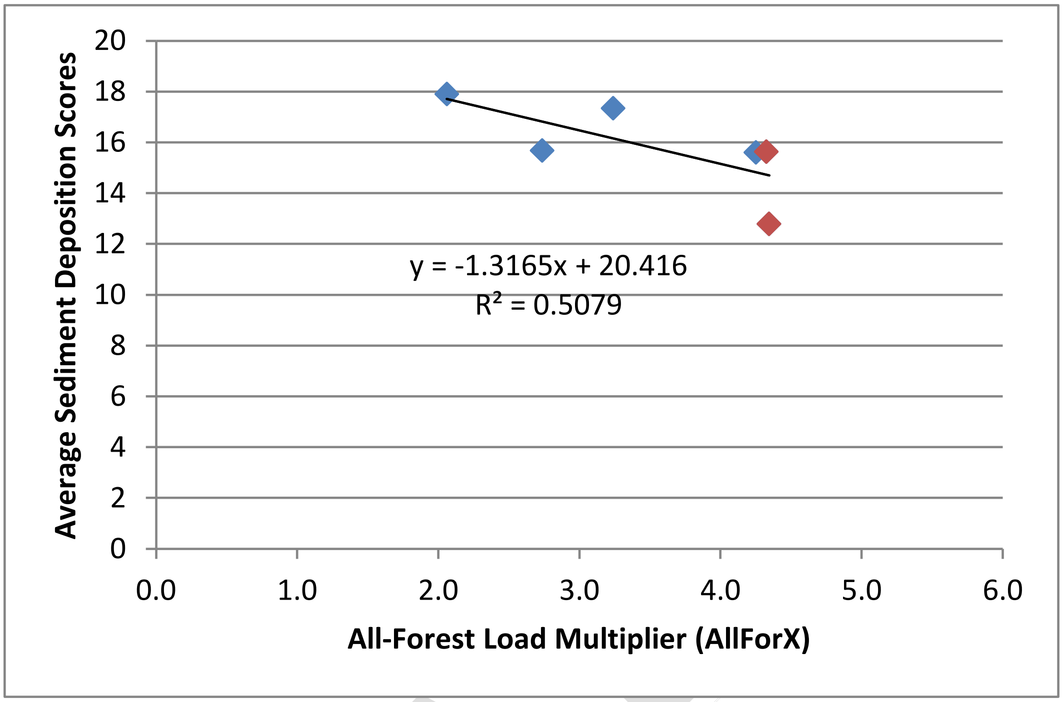


Figure G.2. AllForX vs. Average Habitat Sediment Deposition Scores.

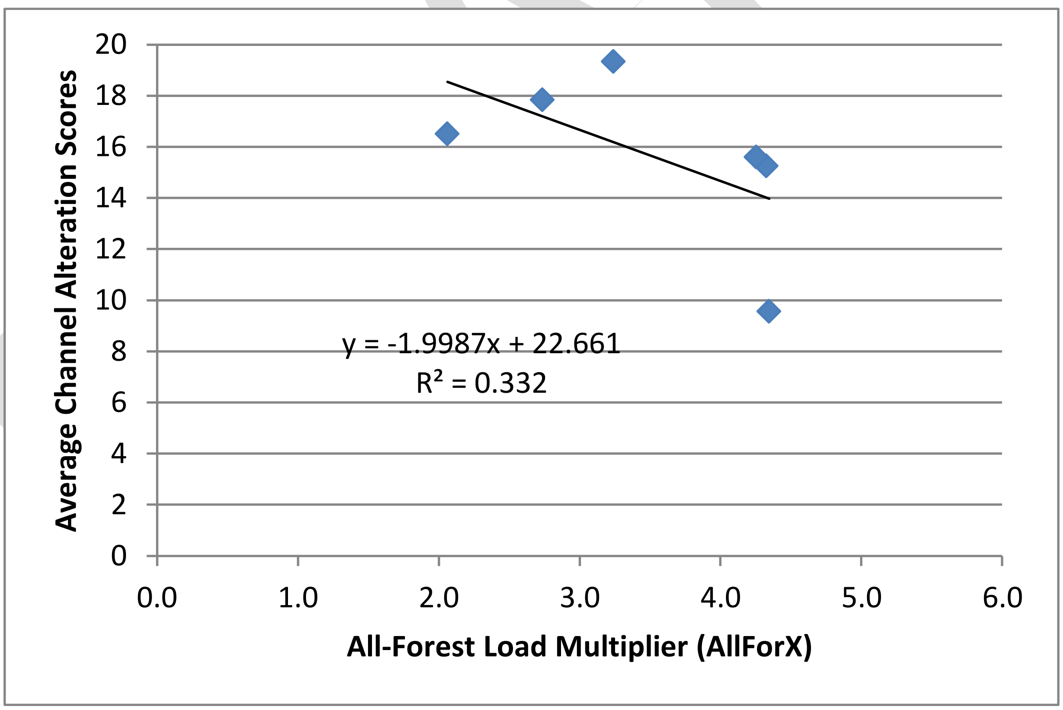


Figure G.3. AllForX vs. Average Channel Alteration Scores.

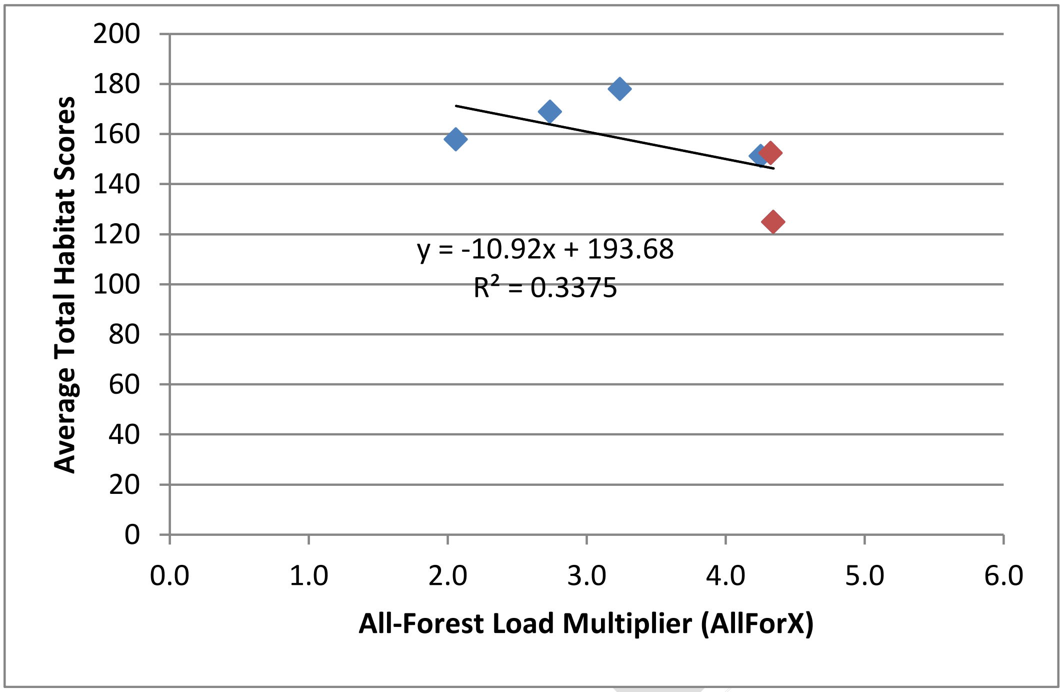


Figure G.4. AllForX vs. Average Total Habitat Scores.